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DESIGN OF A MULTI-SCALE BASE MAP FOR A TILED WEB MAP SERVICE

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Cartography M.Sc.

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Declaration of Originality

I, Taras DUBRAVA, hereby declare that submitted thesis named “Design of a multi-scale base map for a tiled web map service” is a result of my original research. I also certify that I have used no other sources except the declared by citations and materials, including from the Internet, that have been clearly acknowledged as references. This M.Sc. thesis has not been previously published and was not presented to another assessment board.

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Abstract

Raster tile-based map construction is a common approach in building web maps and tiled web map services. However, pre-rendered raster tiles have a lack in flexibility in the context of design, styles and content. Therefore, it influences on the usability of multi-scale base maps and sometimes do not meet user requirement and needs.

The aim of this research is to produce a multi-scale base map with a pre-defined design that meets the requirements of users and set it with an access on the Internet as a tested prototype of a tile-based web map service. It was done through the examination of the related work and examples in multi-scale base map design, and critical review of multi-scale base maps produced by well-known web map providers.

Moreover, an empirical user-study has been developed and conducted with 55 participants. Participants were asked to evaluate the cartographic quality of created multi-scale base map design. Results have shown, that the produced multi-scale base maps contain certain design issues and uncertainties. Consequently, the map design improvements are essential to fulfil target user requirements and needs and to reach usability goals.

Keywords: Multi-scale base map, Aspects of multi-scale base map design, Tiled web map application, Base map for localization and orientation, Base map for thematic support.

List of Abbreviations

3D	Three Dimensional
AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
CC	Creative Commons
CC BY	Creative Commons Attribution-Alone
CC BY-SA	Creative Commons Attribution-ShareAlike
CSS	Cascading Style Sheets
ESRI	Environmental Systems Research Institute
GeoJSON	JavaScript Object Notation for Geographical features
GIS	Geographic Information Science
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HTML	Hypertext Markup Language
ILWIS	Integrated Land and Water Information System
JPEG	Joint Photographic Experts Group (raster image format)
JSON	JavaScript Object Notation
KML	Keyhole Markup Language
KVP	Key-Value-Pair
LGPL	GNU Lesser General Public Licence
LOD	Level of Detail
MIT	Massachusetts Institute of Technology
MVT	Mapbox Vector Tile
OGC	Open Geospatial Consortium
OS	Operating System
OSGeo	Open Source Geospatial Foundation
OSM	OpenStreetMap
PNG	Portable Network Graphics (raster image format)
POI	Point of Interest
REST, RESTful	Representational State Transfer
SDI	Spatial Data Infrastructure
SDK	Software Development Kit
SLD	Styled Layer Descriptor
SOAP	Simple Object Access Protocol Web

SVG	Scalable Vector Graphics (vector image format)
TMS	Tile Map Service
TopoJSON	Extension of GeoJSON that encodes Topology
UCD	User-Centred Design
UE	Usability Engineering
UI	User Interface
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
VGI	Volunteered Geographic Information
WMS	Web Map Service
WMS-C	WMS Tile Caching
WMTS	Web Map Tile Service
WWW	World Wide Web
XML	Extensible Markup Language

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1. Introduction

This chapter presents the context in which this research is set, it describes the research problem and the research scope, and research questions are specified. Furthermore, the outline of the thesis is given.

1.1. Background and problem statement

Google Maps service was launched for public usage in 2005 and since that time it affectedly changed the way people viewed maps (Gibbs, 2015; Gillavry, Brentjens, & van der Vegt, 2012; Muehlenhaus, 2014; Sample & Ioup, 2010). It became a new form of map distribution and all other online map providers soon switched to it (Clouston & Peterson, 2014). The core enabling approach behind the new era of mapping applications was the idea of tile-based mapping. In this technology, the background map had been fragmented into smaller tiled pictures, tiles (Sample & Ioup, 2010). Until now, it remains the basic concept of tile-based web map services.

Currently, the best-know examples of tiled web map services are Google Maps[1], MapBox[2], Bing Maps[3], MapQuest[4], Yandex Maps[5], HERE WeGo[6], OpenStreetMap[7], based on the maps usage statistics (BuiltWith, 2017). All of them and their derivatives, e.g. related map services, are mostly freely available for end users (Wang, 2014) for different purposes: cartographic or non-cartographic, commercial or non-commercial, personal or communal.

Construction of the map with tiles leads to quicker map representation over the Internet, reduced data transmission capacities, and it also gives other benefits when overlaying with thematic foreground map (Clouston & Peterson, 2014).

With technological development, new possibilities to access tiled web maps and services with those maps appeared. Besides already known Application Programming Interfaces (APIs), Web Map Service (WMS), and different web mapping frameworks, a new group of services evolved based on standards and applied tile-numbering schemes. The best-known are: Tile Map Service (TMS) developed by the Open Source Geospatial

[1] https://www.google.com/maps, accessed 31 August 2017
[2] https://www.mapbox.com/, accessed 31 August 2017
[3] https://www.bing.com/maps, accessed 31 August 2017
[4] https://www.mapquest.com/, accessed 31 August 2017
[5] https://yandex.com/maps/, accessed 31 August 2017
[6] https://wego.here.com/, accessed 31 August 2017
[7] https://www.openstreetmap.org/, accessed 31 August 2017

Foundation (OSGeo) and Web Map Tile Service (WMTS) by Open Geospatial Consortium (OGC). It was implemented for custom maps rendering, where the client was able to access exactly the desired map (García, Castro, Verdú, Verdú, & Regueras, 2012).

Currently, many software, especially in GIS domain, which handles geospatial and cartographic data, have nested packages that operate with existing web map services. One of such software is ILWIS[8], a Geographic Information System (GIS) and remote sensing software for both vector and raster processing developed and distributed by ITC (International Institute for Geo-Information Science and Earth Observation) located in Enschede, Netherlands.

For some time ILWIS was using the TMS provided by MapQuest, an online web mapping service provider, as a background map, and it was appreciated by the ILWIS users. Unfortunately, the MapQuest service stopped being free in August 2016 (Colston, 2016), and then the ILWIS programmers changed the URL(web address) used for the background map to the next free available TMS server, which was the TMS provided by OpenStreetMap.

However, the ILWIS users do not find the new background map as nicely styled as the one that was provided by MapQuest. They have difficulty in finding other maps for their study areas that can be used as a background map. Therefore, ILWIS would like to have their own tiled-web map service for their users.

1.2. Research scope, questions and objectives, and innovation

The *main goal* of this M.Sc. research is to produce a functional multi-scale base map with a pre-defined design and set it with an access on the Internet as a tested prototype of a tile-based web map service.

For this project, OSM data will be used as an input for the base map generating. OSM data can be used free of charge, it is simply obtainable and downloadable through the Internet, and highly standardized (Schlesinger, 2015; Zhang & Malczewski, 2017). Furthermore, it includes a worldwide coverage.

It would require long processing times to build a multi-scale base map for the entire world. This is considered as a future step in the practical project part, probably supported by ILWIS professional programmers. This research will focus on the methods of

[8] https://www.itc.nl/Pub/Home/Research/Research_output/ILWIS_-_Remote_Sensing_and_GIS_software.html, accessed 31 August 2017

implementation and the design of a rich base map at different zoom levels. Therefore, the study area will be limited to the Luxembourg country.

The research will focus on the open-source software for producing slippy maps - TileMill[9], which has embedded Mapnik[10] engine for generating, styling and rendering tiles (D. A. Smith, 2016). Mapnik is an open-source mapping toolkit for desktop- and server-based map rendering. Many users of OSM data make use of this toolkit to render it into tiled web maps to serve web map applications (Westra, 2013). Other solutions like server and command line tools, and client-side with GUI applications are not investigated.

There are several specific *objectives* in this M.Sc. research, namely:

- Provide a procedure for styling and rendering of the OpenStreetMap data into a tiled web map service;
- Produce a multi-scale base map for the application, that satisfies user requirements;
- Draw up specifications for scale levels, tiling scheme, content, styling, symbolization, layout, and other technical specifications;
- Build a prototype of a tile-based web map service.

The following *research questions* will be answered:

1) How should the base map be designed to meet the requirements of users of GIS software?

   Sub-questions:

   - How appropriate are the styling settings, that are used by some well-known tiled web map services?
   - How to involve users' wishes and desires into the design directives?

2) How appropriate are TileMill and Mapnik as a software and a tool to style and render OpenStreetMap data?

   Sub-Questions:

   - What is the basic architecture of the prototype tile-based web map service?
   - What is the workflow for tiles generating and rendering?
   - How does the styling work?
   - How does the tiling work?

[9] https://tilemill-project.github.io/tilemill/, accessed 31 August 2017

[10] http://mapnik.org/, accessed 31 August 2017

These M.Sc. research uses already existing and known frameworks, software and tools. However, the base map will be designed on the basis of the author's ideas, osm-bright style[11], the analysis of existing base maps and suggestions and recommendations of users of base maps collected via a survey.

1.3. Outline of the thesis

The thesis is divided into five chapters. Table 1.1 provides a brief contents overview of each chapter.

Chapter 1	**Introduction:** Description of the background and problem statement, the research scope, questions and objectives, and the outline of the thesis.
Chapter 2	**Theoretical foundation:** The essentials of tiled web map services that are important for the further understanding are discoursed. This includes what a tiled web map service in general is, what tile numbering schemes and standards are, and vector tiled map services. An overview of usability studies for web mapping applications is considered. Furthermore, the aspects of the design of a multi-scale base map and a critical review of base maps of existing tiled web map services are presented. Moreover, the usage of OpenStreetMap data are explained in detail.
Chapter 3	**Methodology:** In this chapter the basic methodologies which are used in order to accomplish the practical results are described.
Chapter 4	**Implementation:** In this chapter techniques and tools which are applied in order to achieve the practical result and to conduct the project survey are explained.
Chapter 5	**Results:** This section explores detailed description of study results and the questionnaire outcomes.
Chapter 6	**Conclusion and recommendations:** In the last chapter, the summary is given about the conducted project research. Additionally, the discussion and recommendations are given.

Table 1.1. *Master Thesis structure*

[11] https://github.com/mapbox/osm-bright, accessed 31 August 2017

2. Theoretical foundation

This chapter introduces tiled web map services, its tile numbering schemes, and standards, and vector tiled map services. It includes an overview of guidelines for web map design in the context of usability studies, and describes the evolution of the multi-scale base map in the web mapping environment. It presents related work and examples in multi-scale base map design. Moreover, the aspects of the design of a multi-scale base map are also specified. Conclusion is provided in the end of the chapter.

2.1. Tiled web map services

It has already passed almost 25 years since the first web map through WWW was accessed and became a popular technique of distributing maps (García et al., 2012; Peterson, 2012b, 2014). At the beginning of web Cartography era, different types of web maps were available for users (Antoniou, Morley, & Haklay, 2009; Clouston & Peterson, 2014). Generally, there were two main categories of web maps, static and dynamic (Kraak, 2001), primary static (Neumann, 2012), some of them included certain forms of interactivity which required that time sufficient computer capabilities, high Internet connection quality and user patience (Peterson, 2012b). At some point users were displeased with the map delivery time, instance reaction of the server on executed commands, and loading speed of accomplished results (Clouston & Peterson, 2014; Jenny, Jenny, & Räber, 2008; Muehlenhaus, 2014).

To solve a part of all those issues, Google Maps was one of the first services in web map industry in 2005 which applied AJAX, a tiling technique for maps to enhance the interactivity, where the entire map was divided into seamlessly joined image files (Muehlenhaus, 2014; Peterson, 2012b; Quinn & Gahegan, 2010; D. A. Smith, 2016; Westra, 2013). It changed previously clunky and slow map navigation methods and brought its benefits, which let users move and zoom the map much quicker and in a more efficient way (Sample & Ioup, 2010). Tile-based mapping was the core concept which was solidly settled and applied by other web map service providers (D. A. Smith, 2016). On one side, this approach improved rate for serving the map, helped to speed up the display of the map through the Internet, reduced data transmission volumes and became the most common for map delivery on the WWW (Peterson, 2012b; Sample & Ioup, 2010), but on the other side there was a disadvantage of lacking flexibility in the context of style and content (Schmidt & Weiser, 2012).

Tile-based mapping systems have certain properties, that distinguish them from other types of mapping systems. Sample and Ioup defined those properties:

1) *"Map views are based on multiple discrete zoom levels, each corresponding to a fixed map scale.*
2) *Multiple image tiles are used to virtualize a single map view.*
3) *Image tiles are accessible using a discrete addressing scheme.*
4) *Tiled images stored on a server system, and are sent to the client with minimal processing time"* (Sample & Ioup, 2010).

Tile-based mapping systems are mostly launched through the Internet connection via different services, for example, a tiled web map service. *A tiled web map service* is a web mapping application that provides access to the map, constructed from interconnected map chunks, more known as tiles. Such a tiled web map is also called *Slippy Map*, this definition originally was used by OpenStreetMap.

Tiles are classically pre-processed and prepared in advance on the side of web map server, that renders the map across a fixed set of scales through onward generalization (Clouston & Peterson, 2014). Pre-rendered tiles are one of the vital basics that made web mapping services efficient enough (P. Smith, 2008). The rendered map constructed from tiles can be represented schematically as a tile pyramid (Figure 2.1) (García et al., 2012; Quinn & Gahegan, 2010).

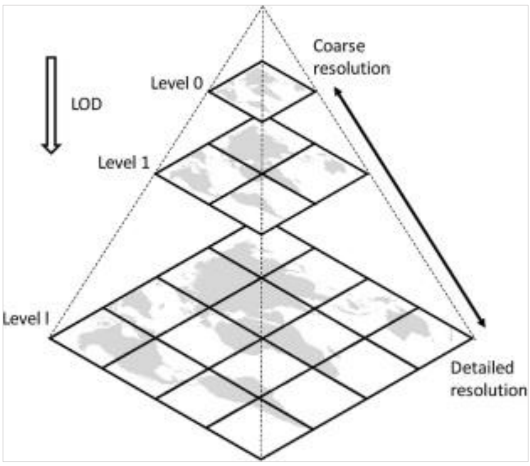

Figure 2.1. *Tile pyramid* (García, Verdú, Regueras, de Castro, & Verdú, 2013)

With the increasing Level of Detail (LOD), also known as zoom level, the amount of displayed data is also enlarging which makes it scale-dependent. Visualized information is adjusted to the given scale through progressive generalization (García et al., 2012, 2013). Currently, the most common file format for tiles is raster, nevertheless, the influence of vector is inevitable which makes vector applications the next generation in tile-based web map construction (Clouston & Peterson, 2014). More about vector tiles in Section 2.1.2.

Most tiled web map services follow *Google Maps convention*:

- Each tile is typically composed of 256x256 pixels, for a total 65.536 pixels (Clouston & Peterson, 2014); A tile is a raster image usually JPEG or PNG file (Masó, Pomakis, & Julia, 2010; Přidal & Žabička, 2008).
- The entire world can be represented in a single map tile on the lowest-scale zoom level (Google, 2017; Peterson, 2012a).
- Each zoom level doubles in both dimensions, so a single tile is replaced by 4 tiles when zooming in (Sample & Ioup, 2010). Tiles form a tile pyramid, sometimes termed as "zoom pyramid" (Přidal & Žabička, 2008).
- Mercator projection on a spherical approximation of the Earth is used, with latitude limits of around 85 degrees (Clouston & Peterson, 2014; Muehlenhaus, 2014; Přidal & Žabička, 2008).

As long as the convention accommodates a slight difference in tile indexing systems, tiles are mutually compatible and can be interchanged between other services (Clouston & Peterson, 2014; Přidal & Žabička, 2008).

Among all available tiled web map services in the domain of map technologies, the most commonly known are Google Maps, OpenStreetMap, MapBox, Bing Maps, MapQuest, Yandex Maps, and HERE WeGo.

2.1.1. Raster tile numbering schemes

A map which is created for multiple scales and broken into tiles, it is not just a set of images but indeed it is a more complex structure which requires certain technical considerations and rules, especially when presenting it on the web or in any application, e.g. GIS application (García et al., 2013).

Setting up tiled web map services requires abidance of the convention, mentioned in the previous section, or standards that in its turn contain certain properties. Those properties can involve the size of tiles, the numbering of zoom levels and tiles, the projection type, the way individual tiles are numbered or otherwise identified, and the method for requesting them.

One of the essential elements of tile-based mapping systems is *a tile numbering scheme* that outlines the discrete addressing of map tiles, the method for generating multiple zoom levels of tiles, and the conversion method between tile addresses and an incessant geospatial coordinate system (Sample & Ioup, 2010).

There are *three main indexing schemes*: Google Maps; Tile Map Service (TMS); and QuadTree (Bine) (Clouston & Peterson, 2014), demonstrated in figure 2.2[12].

Figure 2.2. *Joint example of tile numbering schemes*

As shown in figure 2.2, the primary difference between Google Maps and TMS referencing systems lies in the definition of the tile origin. Both of them use a simple pair of coordinates to address tiles, but for Google, the 'y'-tile coordinates run North to South while in TMS it is vice versa (Clouston & Peterson, 2014; Sample & Ioup, 2010).

Each individual tile is named with the 'y'-tile coordinate and sits within a directory named with the 'x'-tile coordinate. This 'x' directory, in turn, lies within a directory that is named according to the zoom level (Clouston & Peterson, 2014).

Microsoft's Bing Maps uses QuadTree with sequential numbering scheme, from top-left till low-right tile (Sample & Ioup, 2010; Schwartz, 2017). QuadTree keys are used to optimize the indexing and storage of tiles in a database, the two-dimensional tile 'xy' coordinates are combined into one-dimensional strings, called "Quadkeys". The length of a Quadkey string is equal the LOD of the corresponding tile. Quadkey of any tile starts with the Quadkey of its parent tile. As shown in figure 2.3, tile two is the parent of tiles 20 through 23, and tile 13 is the parent of tiles 130 through 133 (Schwartz, 2017):

Figure 2.3. *Bing Maps QuadTree architecture* (Schwartz, 2017)

[12] Credits: MapTiler, Tiles à la Google Maps: Coordinates, Tile Bounds and Projection: http://www.maptiler.org/google-maps-coordinates-tile-bounds-projection/, accessed 31 August 2017

2.1.2. Raster tile standards

Geographic information is an expensive resource and for this reason, standardization is needed to promote its availability and reuse (García et al., 2012, 2013). Standards also point on interoperability, that significantly expands the overall geospatial resource network (Köbben, 2012; Trakas, 2012).

Tiled web map services adhere certain standards of the way tile schemes are communicated (Sample & Ioup, 2010). The best-known standard specifications, also called protocols, are: Tile Map Service (TMS), Web Map Tile Service (WMTS), and the de facto XYZ. These protocols define a tiled web service interface that returns tiles in accordance with the request, means only a part of tiles will be delivered, unlike WMS, where the full-value map is delivered, and where results are usually computed on-the-fly by extracting data from the database (Kefaloukos, Salles, & Zachariasen, 2012; Yeşilmurat & İşler, 2012).

2.1.2.1. Tile Map Service (TMS)

TMS is a standard specification, developed by the Open Source Geospatial Foundation (OSGeo[13]) (Gillavry et al., 2012). It is a simple RESTful protocol for serving map tiles, that places tiles on a grid and refers to their positions using 'x', 'y', and 'z' coordinates, where 'z' is the zoom level, and 'x' and 'y' refer to column and row positions (Westra, 2013). TMS has its official documentation online, provided via the following URL[14].

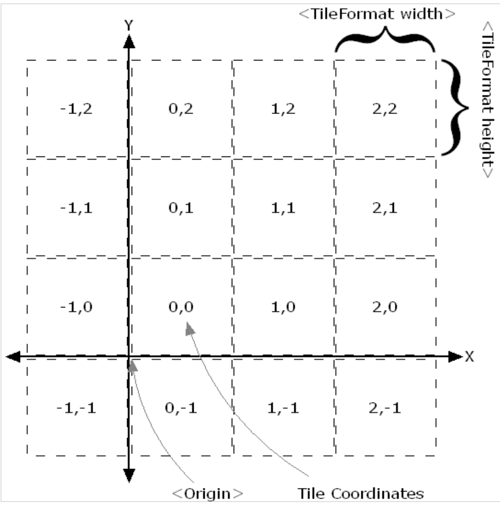

Figure 2.4. *TMS tile matrix*[15]

The TMS specification has gained some level of common usage with a number of servers and clients (Sample & Ioup, 2010). As demonstrated on the left image, TMS uses square tiles, which means, that tile' width and height are equal (Masó, Pons, & Singh, 2010). Protocol allows multiple different tile schemes to be indicated.

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13 http://www.osgeo.org/, accessed 31 August 2017

14 http://wiki.osgeo.org/wiki/Tile_Map_Service_Specification, accessed 31 August 2017

15 Credits: TileMap Diagram: https://wiki.osgeo.org/wiki/Tile_Map_Service_Specification, accessed 31 July 2017

TMS is a protocol defined for map tile exchange which is also used by tile caching servers (Přidal & Žabička, 2008). The protocol supports profiles that specify a map scale and map projection, the tile size may be specified as well. The TMS format supports only a RESTful URL request for tiles. The definition generally requires a URI structure which attempts to fulfil REST principles. The TMS protocol fills a gap between the very simple standard used by OSM and the complexity of the Web Map Service (WMS) standard, providing simple URLs to tiles while also supporting alternate spatial referencing system (Sample & Ioup, 2010).

2.1.2.2. Web Map Tile Service (WMTS)

WMTS Implementation standard provides a standard based solution to serve digital maps using predefined image tiles, request from a server. This protocol was developed by Open Geospatial Consortium (OGC[16]) as the complement of the existing WMS standard (Masó, Pomakis, et al., 2010). Detailed and comprehensive explanations about the standard specifications are available on the official OGC web-page[17].

As shown on the right image, WMTS uses rectangular tiles. The WMTS standard addresses tiles using matrix coordinates, the top-left tile is addressed as (0,0). However, other properties of the tile scheme are possible to change by the service developer (Sample & Ioup, 2010). Moreover, tiles of different scale can have different sizes (Masó, Pons, et al., 2010).

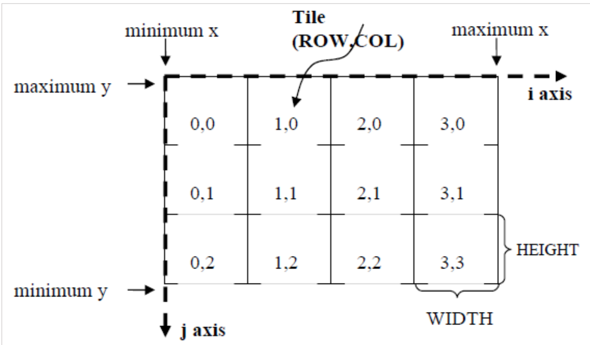


Figure 2.5. *WMTS tile matrix* (Masó, Pons, et al., 2010)

This protocol delivers a standard but flexible way of defining the capabilities of a tile service and how to interface with it. WMTS does not oblige the use of single exact tile scheme, projection, or resolution set. In lieu of, it provides a standard means of defining these properties which mean that a client and a server may be linked together. Several projections are allowed to apply, together with the Geodetic and Mercator projections (Sample & Ioup, 2010).

The map scale is proposed only as an identifier for a given LOD since it is accurate only near the equator. Tile size may vary over the scale, and there may be no tie between

[16] http://www.opengeospatial.org/, accessed 25 August 2017

[17] http://www.opengeospatial.org/standards/wmts, accessed 5 August 2017

the tile matrix dimensions and the scales. Certainly, the allowed level of flexibility increases the difficulty of writing a general client to support a general WMTS server. To diminish this issue, the WMTS standard supports a set of server-approved scale sets and with its implementing, the server becomes compatible with a wider range of clients (Sample & Ioup, 2010). WMTS supports request encodings: KVP, RESTful, and SOAP for accessing tiles. Moreover, WMTS is used when WMS does not provide the desired quality of service and cannot produce maps on-the-fly with an appropriate quality (Vanmeulebrouk, de Ruijter, Bulens, & La Riviére, 2012).

Many SDIs are migrating their tiled services to make them compatible with WMTS standard (Masó, Pomakis, et al., 2010). WMTS is inspired by the OSGeo TMS Specification, WMS-C proposal and other similar initiatives, such as Google Maps and NASA OnEarth (García et al., 2013; Masó, Pomakis, et al., 2010).

2.1.2.3. The de facto XYZ

This standard, also known as Slippy Map Tilenames or The de facto OSM standard. It responds to the following properties:

- The tiles' size is 256 × 256 pixel, with PNG file extension
- Each zoom level is a directory, each column is a subdirectory, and each tile in that column is a file
- Filename (URL) format is http://server/…/yourmap/zoom/x/y.png

2.1.3. Vector tiled map services

Employment of vector graphics in web mapping industry is not a new topic (Lienert, Jenny, Schnabel, & Hurni, 2012). Researchers demonstrated that in specific cases raster images are inadequate and there are limitations of raster-only mapping application (Antoniou et al., 2009; Bertolotto, 2007). Therefore, some mapping companies, e.g. Google Maps with its sufficient financial support and MapBox with its initiatives, were able to move towards applying vector tiles for web mapping purposes (Clouston & Peterson, 2014).

Vector tiles, tiled vectors or vectiles are chunks of geographic features in vector form, that are transferred over the WWW. *Vector tiled map services* can be defined as map applications built from vector tiles, that use geometric primitives and are precisely rendered in real-time.

The full process of creating tiles from vector data has many similarities with raster tiles creation. The main difference is that vector data is drawn into tiled images in lieu of cutting image tiles from source data (Sample & Ioup, 2010). Furthermore, Sample and Ioup defined some unique things which distinguish tiling vector data from tiling imagery, e.g. storage space, processing time, and overview images (Sample & Ioup, 2010). Besides, there is no need to create tiles in advance and store permanently for distribution as it was implemented for raster tiles. Vector features must be renderable, this will ensure its visualization in the map window (Sample & Ioup, 2010).

Tiles may be rendered as they are requested. This basically means that generating tiles is done just-in-time, i.e. on-the-fly rendering procedure (Antoniou et al., 2009; Köbben, 2012; Sample & Ioup, 2010).

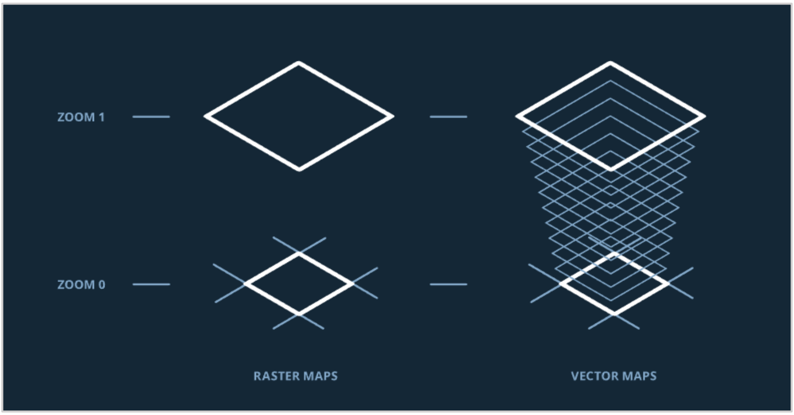


Figure 2.6. *Difference in transition between raster and vector tiled maps*[18]

In figure 2.6 the general scheme of raster and vector tiled maps is demonstrated. In contrast to the of raster tiled map, where the transition between zoom level zero and one is done within one step, a vector tiled map can have a bit more intermediate stages in transition actions which make it more smooth and onward.

2.1.3.1. Standards and approaches

Adversely to standards for raster tiles, there is no dominant standard for vector tiles. Approaches can differ in their URL format, data splitting format, packaging of styling information, and support for projections another than web Mercator. However, MapBox is one of web map providers which regularly deploys vector tiles.

[18] Credits: MapBox https://www.mapbox.com/maps/, accessed 25 August 2017

The MapBox Vector Tile Specification provides information about file formats and extensions, projections and bounds, and the internal structure of vector tiles. Detailed explanations about this standard is available on the official MapBox web-page[19].

Besides MapBox specification, OpenMapTiles.org project offers a Vector Tile Schema which describes how the vector data is organized into different thematic layers and which attribute and values each layer contains. Details about OpenMapTiles Vector Tile Schema are available through the following link[20]. These projects contain also Open Map Styles for tiles.

File formats which are commonly used for vectiles are MVT, JSON, GeoJSON, TopoJSON and other (OSGeo, 2017). List of the most typical software applied in vector tiling includes Mapbox Studio, Kartograph, ArcGIS Pro, Mapzen, Kosmtik, Tangram and many others.

For serving vector tiles there are few server options that have been developed. These options were discussed from the perspective of strengths and weaknesses by Norman in his web blog in 2016 (Norman, 2016). The author highlighted following choices: Node-Mapnik based, Tilezen tileserver, Tegola, t-rex, TileStache, Tilemaker, VectorTileCreator. In the end of author's article, the comparative table of servers was derived.

2.1.3.2. Pros and cons

The advantages and disadvantages of tile creation using vector data are emphasized and presented in the table 2.1.

Pros	Cons
Vector tiles obey smoother and softer transition between close zoom levels rather than raster tiles (MapBox, 2017). Also, it ensures more efficient downloads and more rapid updates (Mapzen, 2017).	On-the-fly or dynamic generalization is still an unsolved cartographical challenge (Antoniou et al., 2009; Jones & Mark Ware, 2005; Yang, Purves, & Weibel, 2007).
On-the-fly rendering decreases the storage requirements considerably (ArcGIS, 2017; Sample & Ioup, 2010).	On-the-fly rendering diminishes the performance of the system (GeoSLab, 2016; Sample & Ioup, 2010).
Vector maps are nearly a quarter of the size of traditional raster implementations. This provides greater performance in	Approximation of vector features is not always possible because of its high-dimensionality and complex geometry,

[19] https://www.mapbox.com/vector-tiles/specification/, accessed 30 August 2017

[20] https://openmaptiles.org/schema/, accessed 30 August 2017

low-bandwidth environments and greater cost savings where bandwidth is costly (MapBox, 2017).	therefore there is no guarantee that a vector feature may be represented on a screen (Sample & Ioup, 2010).
Styling and design flexibility (MapBox, 2017; OSGeo, 2017; Peterson, 2014). Vector graphics, likely SVG is preferred by many web cartographers (Jenny et al., 2008) and this is the most suitable format for web mapping (Neumann, 2012).	The geographic data may need to be pre-processed, which allows the client to do the drawings, that are required. Therefore, vector tiles should only be used for rendering (OSGeo, 2017).
A broad variety of data types, that can be automatically organized and searched through the database. Moreover, not much of the functionality, provided by a database is required by a tiling system (Sample & Ioup, 2010).	Features are duplicated between tables. When using data from a database, there is a need to create multiple tables to store data for different scales, because only one index on a table may be clustered, and the query on bounds and scale requires other optimization depending on the parameters (Sample & Ioup, 2010).
Vector tiles are relatively small, allowing global high-resolution maps, fast map loads, and efficient caching (MapBox, 2017; Peterson, 2014; D. A. Smith, 2016).	GeoJSON is not always suitable for use because it shrinks weird on large-scale zoom levels and the re-encoding work necessary at the client and server ends (Migurski, 2013).

Table. 2.1. *Advantages and disadvantages of vector tiles*

To sum up, vector tiles provide a cutting-edge approach in tiled mapping. However, the domain of vector tiles is ongoing and highly important research topic in Cartography which requires more advanced investigations.

2.2. Guidelines for the web map design in usability studies

Since the first web mapping site was launched and introduced to the public, the interaction efficiency and quality between user and map window affectedly evolved and improved. With technological enhancement and progressive analysis and understanding of user-side, web map developers significantly enhanced the usability and GUI, operational engine, functions and tools possibilities, fulfilled most of user needs and requirements, and above all the cartographic part of each web mapping provider was also refined (Muehlenhaus, 2014; Neumann, 2012).

In the earliest decade of web map services, the map window was shared between different links. Currently, the map is the essential content of the page and it occupies an appropriate amount of space in the browser window on the screen (Jenny et al., 2008).

Web maps are usually used for locating places and for planning visits to unknown places (Nivala, Brewster, & Sarjakoski, 2008).

In the figure 2.7 and 2.8 it is visible how the web mapping UI and the map itself were modified and developed, on the example of Google Maps and MapQuest.

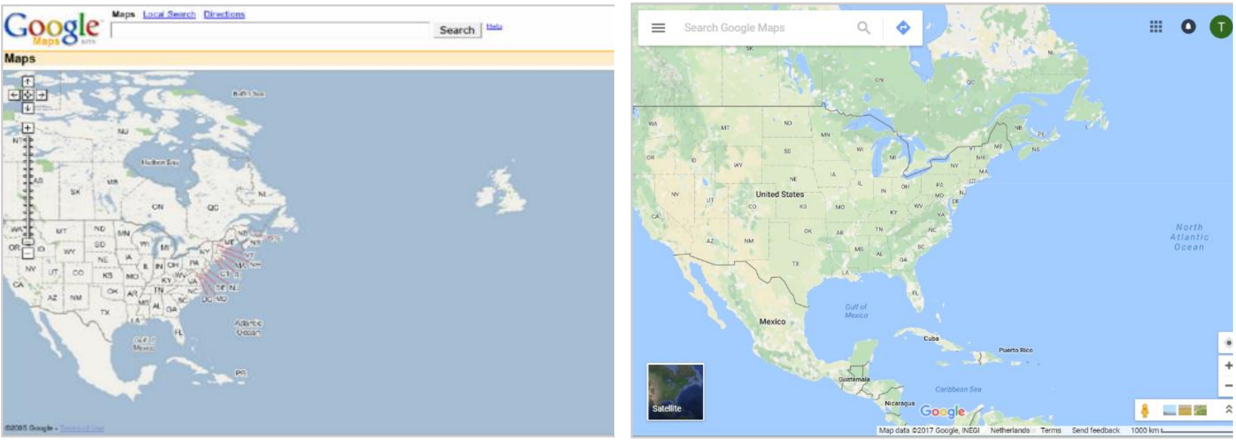


Figure 2.7. *Difference between Google Maps initial and current versions (2005-year[21] on the left and 2017-year on the right)*

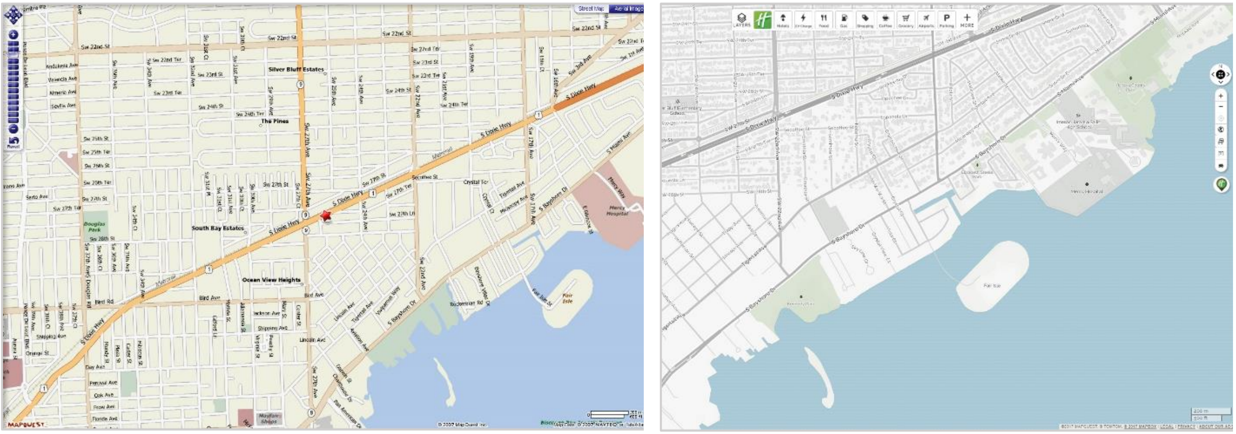


Figure. 2.8. *Difference between MapQuest older and current versions (2007-year[22] on the left and 2017-year on the right)*

The map fragments (Figure 2.7 and 2.8) show evident differences on the front-end side, however, web map providers have also applied a tremendous number of changes on the back-end side of the map application, i.e. search operations and service functionality, user profiles, content management etc. This has enlarged the usage popularity and amount of visitors for a certain web map. Increasing the amount of web mapping site users leads particularly to more user research, usability studies and evaluations (D. A. Smith, 2016; van Elzakker & Forrest, 2014; Wang, 2014), which in its

[21] Credits: ICA Commission on Map Design: http://mapdesign.icaci.org/2014/04/mapcarte-116365-google-maps-by-google-2005-present/, accessed 12 August 2017

[22] Credits: Carlos J. Arboleya, Jr. P.A.: http://arboleyalaw.com/directions.html, accessed 12 August 2017

turn, transformed Cartography from supply-driven into demand-driven (van Elzakker & Forrest, 2014).

An advanced usability evaluation of four web mapping sites (Google Maps, MapQuest, MSN Maps & Directions, and Multimap[23]) was performed by Nivala *et al.* (Nivala et al., 2008), in which the group of researchers identified 343 unique usability problems, based on experts evaluations and user tests. The problems included: user interface, map visualization, map tools and search operations. From the obtained problems and qualitative information, the research group suggested some design guidelines for web mapping sites. Authors provided design guidelines for the user interface, map, search operations, help, and guidance. The most important suggestions for the map visualization was stating that maps should be simple and intuitive and pleasant to use; colours should be in harmony; information for each map scale should be appropriated separately; information about data accuracy and validity should be provided; scale increments should be gradual, allowing users to follow a specific location while zooming in and out; scale ratios should not be used, instead, scale should be indicated by commonly used terms (such as street level, city level, country level etc.).

In 2008 a group of researchers led by Jenny *et al.* (Jenny et al., 2008) from ETH Zurich published a scientific paper where they discussed "Map Design for the Internet". In their research, four reasons of digital map design relevance were defined: the map should be legible at a glance; map information must be unambiguous and easy to remember; and finally, the map reader must trust the map. The group of scientists proposed guidelines for web map design, based on the researches' mapping experience and analysis of Internet user behaviour. The guidelines involve next touchstones which should be taken into account: special user needs; anti-aliasing; readable signatures and symbols: dimensions and distances; generalization; colour space and value, transmission and display.

In the sense of multi-scale base maps, there was important instruction for applying *anti-aliasing*, that improves graphical appearance and increases readability. Anti-aliasing is used to add some natural character to digital imagery via smoothing minced edges of map elements. This technique is also applied when vector objects are converted into raster images for display on the screen. Moreover, such procedure requires relatively complex time-consuming algorithms for a real-time rendering, which may lead to increasing hardware requirements. Also, it is important for optimum readability to adapt the symbolization of graphical objects to the low screen resolution. Furthermore, the way to improve readability is to simplify shapes and reduce information density, i.e. symbols

[23] MSN Maps & Directions and Multimap were merged into Microsoft's Bing Maps

must be more differentiated, map feature classes must be easily distinguishable, and dashed lines must be used carefully.

Last but not the least are fonts and colours. Text labels must be easily legible and type should be optically beautiful, regular and bold typefaces are more readable, and a limited amount of type families must be used. Using larger colour contrasts or reducing the number of classes might be beneficial to minimize the potential of confusing between map feature classes. Some of these instructions will be applied in the practical implementation.

In the article provided by Neumann (Neumann, 2012), the author indicated that by using user profiles, personal filters, and personal styling and symbolization, users can personalize, configure, and design their own maps, which is for instance implemented by mapping companies like MapBox Studio[24] or Snazzy Maps[25]. Furthermore, the author provides an example with WMS, which allows personal styling by providing a Styled Layer Descriptor (SLD) file.

There was published an article on a topic "Usability evaluation of Public Web mapping sites" by the researcher from China in 2014 (Wang, 2014). The author employed Usability Engineering (UE) methods, such as questionnaires and task tests, which helped to discover usability problems of four web mapping sites (Google Maps, Bing Maps, MapQuest, and Yahoo Maps), examine the problems quantitatively and offer guidelines and suggestions for the future design of public web map sites. In the visualization section, the author was highlighting, that there is always a gap between the designers and users, it is difficult to balance users' needs and designers' ideas. However, the visualization of the web mapping sites would be a complex issue for map designers.

In 2014 there was published a book chapter by van Elzakker *et al.* (van Elzakker & Forrest, 2014) as the reflection on Nivala *et al.* article. The most important idea in the book chapter was emphasizing, that it is no longer costly to interactively yield several types of cartographic design solutions. Furthermore, product updates can be performed with fewer efforts, in a shorter time and more frequent update intervals (Neumann, 2012), and online cartographers can control the entire map design (D. A. Smith, 2016).

[24] https://www.mapbox.com/studio/, accessed 30 August 2017

[25] https://snazzymaps.com/, accessed 25 August 2017

2.3. Multi-scale base map

Originally, *a base map*, which was mostly manually composed or was a rudimental topographic map, had an aim to provide *location reference* to the thematic layer uploaded or created by a user. Base maps are also aiming to improve the communication between custom and thematic contents (Foerster, Stoter, & van Oosterom, 2012; Huang & Gartner, 2012; Poppe & van Elzakker, 2006).

At the beginning, all base maps mostly looked the same. A slight change was proposed by developers who used hard-coded filters to modify map tiles: colorize, desaturate or blur them (Schmidt & Weiser, 2012).

After the progress of web map service development, a base map attained more specific meanings (Schmidt & Jörg, 2012). Base maps became to be spread as tiled web map services. Services afford *location reference* to the data placed upon them, however, styles and content of base maps are often not simplified or adjusted towards the project constraints, user wishes, and desires (Foerster et al., 2012).

In our time existing base maps are collected from different sources and have changing data coverage (Schmidt & Jörg, 2012). Usually, base maps are generated on the synthesis of public and commercial data (Schmidt & Weiser, 2012), though some projects involve only open or free accessible data. Such core spatial data forms the basis of a Spatial Data Infrastructure (SDI) (Steiniger & Hunter, 2012). In this aspect cartography and implementation of community base maps is an evolving process, where operational framework will rely on vector data from the community, rather than bringing in raster cache tiles (Hardy & Watkins, 2012).

Some results on the way to reduced and simplified styles for use in thematic maps were implemented by GIS companies (e.g. ESRI), which offered base maps for web mapping (Schmidt & Jörg, 2012).

Figure 2.9 shows examples of base maps presented from ESRI's ArcGIS Online through ArcGIS.com (Hardy & Watkins, 2012). A list with 10 possible multi-scale base maps is demonstrated and includes: Imagery, Imagery with Labels, Streets, Topographic, Dark Grey Canvas, Light Grey Canvas, National Geographic, Terrain with Labels, Oceans and OpenStreetMap.

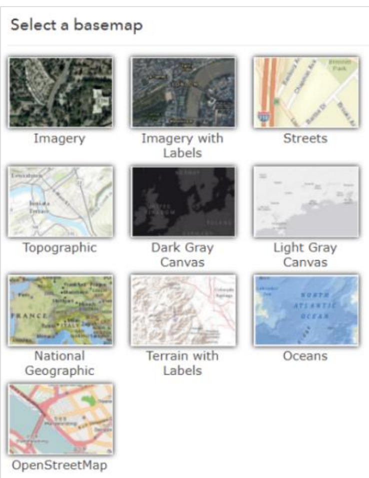


Figure 2.9. *ESRI base maps*

The intention of developers was to produce the variety of maps to meet the majority of user's needs defined by the application and the type of the working data they are using (Hardy & Watkins, 2012). But on the other side, it is also not always possible to fulfil all of user's needs because of the large number of people that use maps (Nivala et al., 2008). Therefore, the user started to play a centre role in the implementation of map-related applications or services and consistent usability evaluation within the development and post-development processes to fulfil user requirements (Koua & Kraak, 2004). Moreover, user and usability research studies became feasible and their importance increased enormously, and remain popular at current time (Khan & Adnan, 2010; van Elzakker & Forrest, 2014; Wang, 2014).

User-centred design (UCD) is a part of user research studies. The purpose for UCD is driven by the need for on-demand maps, which might be exploited by the user, who can certainly have a need, a profile, some preferences about the map, and a context in which the map might be tested (Balley et al., 2014; Delikostidis, 2011; Poppe & van Elzakker, 2006; Roth, Ross, & MacEachren, 2015). All these parameters are also known as *user requirments* and essentially the cartographer's role is to design a map which best suits those requirements, which are crucial in map making process (Balley et al., 2014).

One of the challenges of user research is to consider user's inputs in relations with their requirements. This may lead to detect the most relevant background content and inter-theme relationships that are important to visualize on the map (Balley et al., 2014). In GIS software, the combination of a background topographic layer, e.g. base map provided by a tiled web map service, with a thematic layer, created by the user in the foreground, is known as *cartographic mash-up* (Balley et al., 2014; Hardy & Watkins, 2012).

Mash-ups often cannot show the spatial and semantic relationships between themes, which requires conflation tools and map design skills which are not demonstrated by every mash-up author (Balley et al., 2014). Nevertheless, mash-ups provide a target set of spatial information to the user (Hardy & Watkins, 2012; Hu, 2012; Huang & Gartner, 2012; Stefanakis, 2012).

For overlaying purposes the background map needs to have certain opacity level. This study was explicitly described by Clouston and Peterson in 2014 in their research on a topic "Tile-Based Mapping with Opacity" (Clouston & Peterson, 2014). For other purposes multi-scale base map may involve: localization, orientation, and thematic support (Foerster et al., 2012; Poppe & van Elzakker, 2006).

2.3.1. Related work and examples in multi-scale base map design

Nowadays with a fluent accessibility to the data and developing tools, such as open source software and libraries, guidelines and tutorials, the creation and design of maps became a much easier and attainable process, which is covered by the core of Neocartography[26] (Cartwright, 2012; Faby & Koch, 2010; Kraak, 2011). In its concept, maps are produced by non-cartographers and started to be a part of the art and design, rather than a strictly limited procedure of visualizing geospatial data for certain purposes. People commenced to upload their own, mostly static or animated maps to the global sharing media platforms like Instagram[27], Flickr[28], Pinterest[29] and many other (Caquard, 2014; Tsou, 2015).

On the other hand, consequences of technological revolution in cartography acknowledged that maps are not static products anymore (van Elzakker & Forrest, 2014), and moreover, benefits and possibilities of WWW must be involved in the process of map creation and distribution. Therefore, the workflow of designing a web map turn into a collaboration between people of various specialities, e.g. cartographers, users' researchers, computer scientists, designers etc. Such union ensured more advanced and efficient results in the creation of web map applications, and particularly in the design and styling.

In this section, some significant examples of multi-scale base map design and styling are presented. The examples are also considered as inspiration sources.

1. MapBox Studio[30] by MapBox. MapBox studio is an online platform for managing geospatial data and designing custom map styles. It allows a user to customize the map styles, visualize own data, develop specifications and functionality to the map and find inspiration. More about MapBox Studio can be found on the official manual page[31].

The main menu bar includes following options: Home (to get information about account and quick links to Styles, Tilesets, and Datasets pages), Styles (to create, manage, and edit map styles), Tilesets (to create, upload and manage tilesets), Datasets (to create, upload and manage your datasets), Stats (to see map views and account usage in real

[26] http://neocartography.icaci.org/, accessed 31 August 2017

[27] https://www.instagram.com/, accessed 31 August 2017

[28] https://www.flickr.com/, accessed 31 August 2017

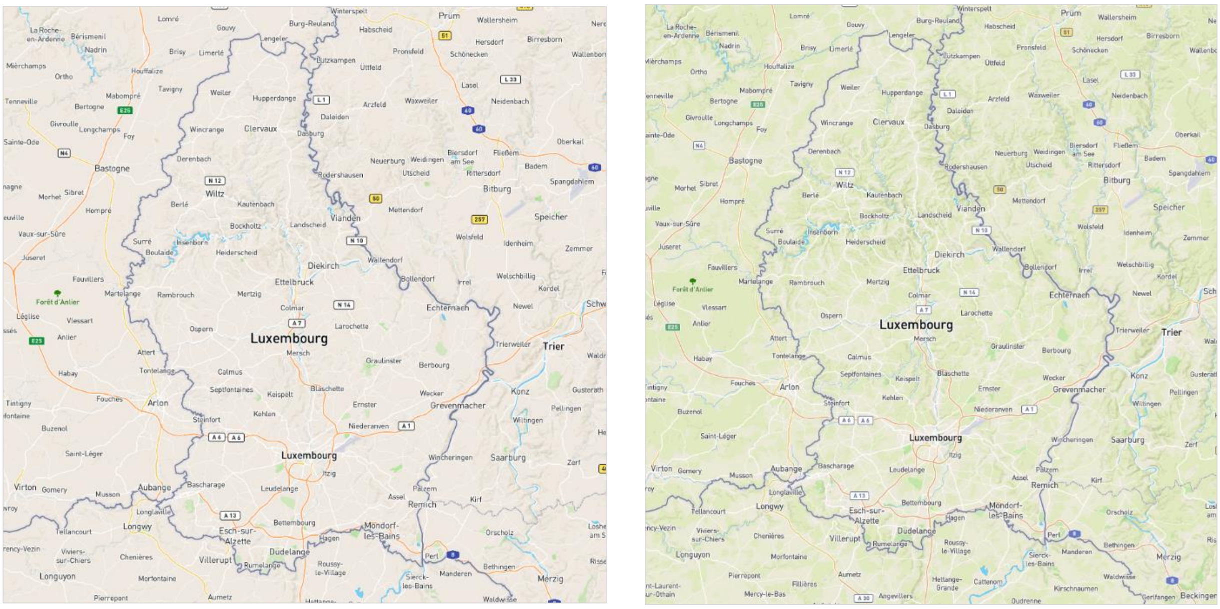
[29] https://www.pinterest.com/, accessed 31 August 2017

[30] https://www.mapbox.com/studio/, accessed 31 August 2017

[31] https://www.mapbox.com/help/studio-manual/, accessed 31 August 2017

time), Classic (to view classic styles and Mapbox Editor projects), and account (to manage account billing, security, access tokens, and more).

Styles menu includes 10 MapBox default styles available for users, namely: Streets, Outdoors, Dark, Light, Satellite, Satellite Streets, Navigation Preview Day, Navigation Preview Night, Navigation Guidance Day, and Navigation Guidance Night. Some of the named examples, for the area of Luxembourg, are shown in figure 2.10.



Streets *Outdoors*

Figure 2.10. *Examples of base maps provided in MapBox Studio*

Additionally, all styles are possible to use right away by integrating it into an application. For platforms, such as Mapbox GL JS, Android SDK, and iOS SDK it is possible through the style URL and access token, for Leaflet via URL with the L.TileLayer class. Moreover, there are ways to use it with other mapping software. It is possible to use styles in GIS apps, e.g. ArcGIS, Tableau, CartoDB, and Fulcrum, or use as a Mapbox WMTS Service in ArcMap or QGIS.

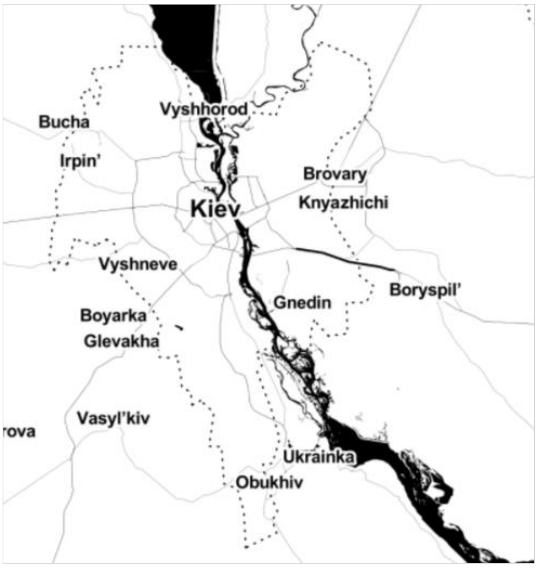
2. Stamen[32]. Stamen is a provider of visualization and analytics design and strategic data communication for private and public sector clients across industries. They took part in projects for designing styles for Microsoft, Google, Pinterest, Yandex, the Golden Gate Parks Conservancy, the 2012 London Olympics, and many others. Library with mapping projects which are available online could be accessed via this page link[33].

[32] https://stamen.com/, accessed 31 July 2017

[33] https://stamen.com/work/maps-stamen-com/, accessed 31 July 2017

Stamen comprises a group of maps, where advanced styling techniques for OSM data were applied. All of them are released under a Creative Commons Attribution (CC BY 3.0) license and could be accessed through this link[34].

In figures 2.11-2.14 the most relevant designed tiled maps are demonstrated, on the example of City of Kiev, Ukraine. The list includes following styles: Toner, Watercolour, Terrain, and Burning maps.



Toner map represents a high-contrast B&W (black and white) map and is featured in Stamen Dotspotting[35] project.
Creators say that this map is perfect for data mashups and exploring river meanders and coastal zones.
It is also available in six flavours: standard toner[36], hybrid[37], labels[38], lines[39], background[40], and lite[41].
Toner Map, Ninth zoom level

Figure 2.11. *Stamen Toner map*

In this case, developers tried to imitate hand drawn maps.
Stamen watercolour map applies raster effect area washes and organic edges over a paper texture which add warm pop to any map.
Watercolour was inspired by the Bicycle Portraits[42] project.
Watercolour Map, 11th zoom level

Figure 2.12. *Stamen Watercolour map*

[34] http://maps.stamen.com/, accessed 31 July 2017
[35] http://dotspotting.org/, accessed 31 July 2017
[36] http://maps.stamen.com/toner/, accessed 31 July 2017
[37] http://maps.stamen.com/toner-hybrid/, accessed 31 July 2017
[38] http://maps.stamen.com/toner-labels/, accessed 31 July 2017
[39] http://maps.stamen.com/toner-lines/, accessed 31 July 2017
[40] http://maps.stamen.com/toner-background/, accessed 31 July 2017
[41] http://maps.stamen.com/toner-lite/, accessed 31 July 2017
[42] http://www.dayonepublications.com/Bicycle_Portraits/Home.html, accessed 31 July 2017

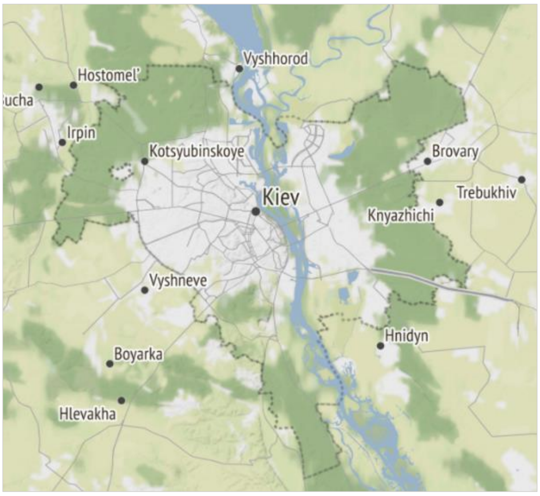


Figure 2.13. *Stamen Terrain map*

This map features hill shading and natural vegetation colours, which may assist in orienteering.

The map shows advanced labelling and linework generalization of dual-carriageway roads.

Terrain map available in four flavours: standard terrain[43], labels[44], lines[45], and background[46].

Terrain Map, 10^{th} zoom level

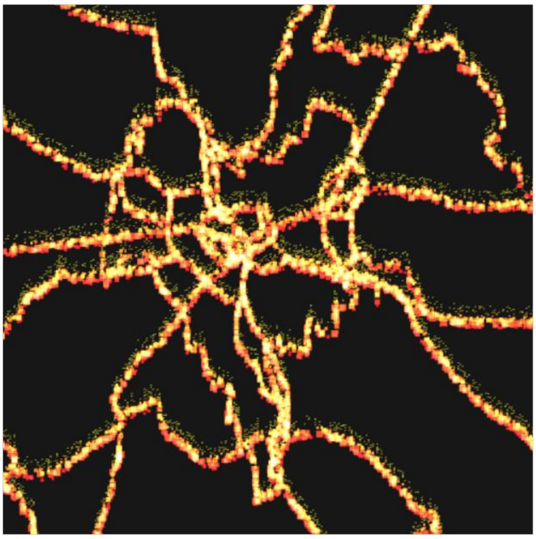


Figure 2.14. *Stamen Burning map*

This "heat map" uses toner-lines as the foundation on which to draw fiery animations. With this map, Stamen shows that maps don't have to lie still on the screen anymore, and then it is possible to use the whole world as a canvas for interaction and movement.

Map launching requires a WebGL-enabled browser.

Burning Map, Ninth zoom level

The first three maps include an API, which let user to apply Stamen tiled maps elsewhere. To use these maps users need to include Stamen JavaScript alongside user's preferable mapping library, for instance, ModestMaps, Leaflet, OpenLayers, or Google Maps API. Libraries and applications understand the notion of map URL templates. Stamen has their own template: http://tile.stamen.com/toner/{z}/{x}/{y}.png

Tiles were made available as part of the CityTracking[47] project, funded by the Knight Foundation[48], in which Stamen was building web services and open source tools to display public data in easy-to-understand, highly visual ways.

43 http://maps.stamen.com/terrain/, accessed 31 July 2017

44 http://maps.stamen.com/terrain-labels/, accessed 31 July 2017

45 http://maps.stamen.com/terrain-lines/, accessed 31 July 2017

46 http://maps.stamen.com/terrain-background/, accessed 31 July 2017

47 http://citytracking.org/, accessed 31 July 2017

48 https://www.knightfoundation.org/, accessed 31 July 2017

3. Basemap.at[49]. This WMTS project was intended to offer an up-to-date and harmonized web base map, which covers the whole state of Austria, where primary administrative data was used. This data was maintained by institutions, which also created it, and this is considered as the main advantage. These institutions are required by law to create the base data, which was expected to get a high level of data quality (Schmidt & Jörg, 2012).

In order to achieve a country level of harmonized data and styles, Basemap.at included geographic data of all federal provinces, which had their own services with province-specific renderings restricted to their own territory. So, in this project there was no need to create new data (Schmidt & Jörg, 2012).

The whole project was implemented as a WMTS in web Mercator (Auxiliary Sphere) and released under the CC-BY 3.0 AT license, which allows the distribution of the map for private and commercial usage with no charge.

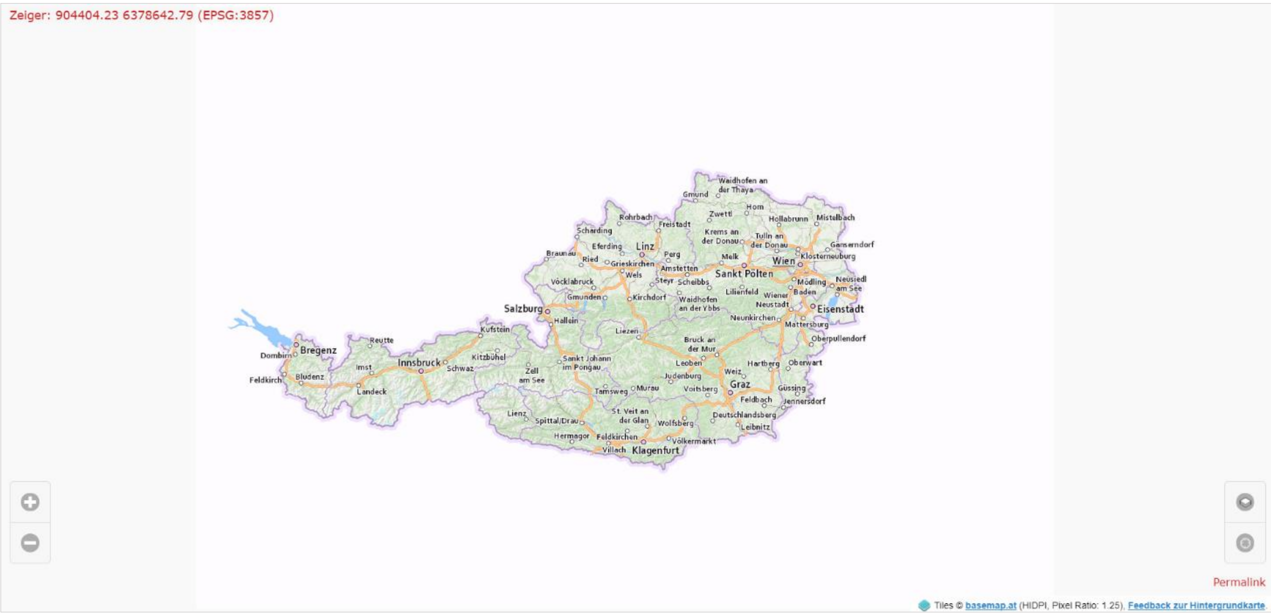


Figure 2.15. *The main map page with Austrian map of Basemap.at project*

Figure 2.15 shows the map of Austria with predefined styles of map content. It includes landscape layer with terrain, transportation network, administrative borders (districts, districts, and municipalities), hydrographic component and settlements. Certain objects are appropriated with labels, symbols or names.

Basemap.at project team involves cartographers, whose role was to optimize the final map, to certify the quality of communicating and visual parts (Schmidt & Jörg, 2012).

[49] https://www.basemap.at, accessed 31 August 2017

Additionally, basemap.at has a functional button called "Kartenbenenauswahl", where the user is able to switch between proposed base maps and other substyles (Figure 2.16). Furthermore, it is possible to activate additional layer called "Schichten", which adds supporting overlays to any of the previously listed maps.

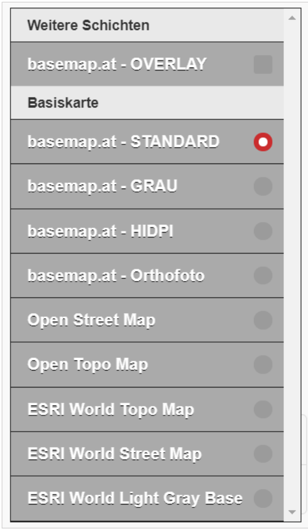
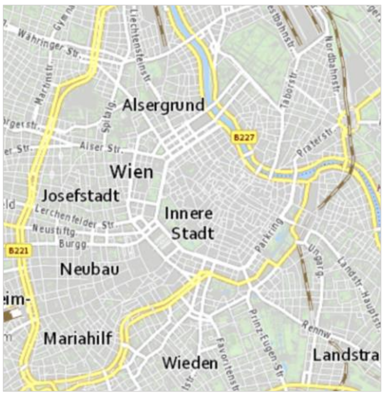


Figure 2.16. *Menu with base maps styles*

The Standard map has a harmonized and engaging colour palette, progressive and smart generalization algorithm, and useful and practical terrain layer. It also involves advanced buildings labelling at large-scale zoom levels and forward-thinking transition styles on large-scales, demonstrated in figure 2.17.



13th zoom level

14th zoom level

Figure 2.17. *Advantages of the "Standard Map" of the basemap.at project*

A shortcoming of the Standard map the place labelling is overcrowded on middle-scale zoom levels. Also unsuitable symbolizers for cities and towns were applied. Furthermore, at certain zoom levels, white and pink circles, that correspond to settlements, are difficult to distinguish and dim against the background, figure 2.18.

Ninths zoom level — 12th zoom level — 10th zoom level

Figure 2.18. *Disadvantages of the "Standard Map" of the basemap.at project*

Also, the used font style is not sufficient which sometimes shows bad labels readability.

Merging of letters. 'i' and 't' in the second word, 'r' and 'i' in the fifth word

Big distance between 'm' and 'a ' in the first word

Merging of letters 'c' and 'h' in the first word

Obscure place name

Figure 2.19. *Issues with the font style of the "Standard Map" of the basemap.at project*

To sum up, at middle scale zoom levels, the base map does not look pure and consistent. It requires improvements towards the level of detail and labelling automated process.

4. WebMapService of World with OpenStreetMap-Data[50]. This project was completed and conducted by the Chair of Geoinformatics/GIScience at the University of Heidelberg located in Germany in 2010. Developers created WMS with style alternatives applied to the entire world, where data was extracted from OSM data source. The service provides users with advanced web map functionality: searching bar; panning tool; get information about the feature; set or clear the marker; measure distance or area.

[50] http://www.osm-wms.de/, accessed 30 July 2017

Figure 2.20. *The home page of WebMapService of World with OpenStreetMap-Data*

The blue window, close to the top-right side of the map view allows a user to switch between four style types of a base map view and additionally apply overlays, figure 2.20. The first style "OSM-WMS worldwide" was produced by the cartographers of this project, all other alternatives inherit typical OSM styling schemes, e.g. Standard, Cycle Map, unfortunately, the last style was out of service. This WMS was deployed in other applications, e.g. OpenRouteService[51] and osm-3D[52].

The "OSM-WMS worldwide" map has an advanced hill-shade layer for Europe, which also fades bright map colours at certain zoom levels, demonstrated in the figure 2.21. Furthermore, map feature classes are clearly distinguishable between each other.

Figure 2.21. *The "OSM-WMS worldwide" base map with the hill-shading (left) and without hill-shading (right), seventh zoom level*

[51] https://www.openrouteservice.org/, accessed 30 July 2017

[52] http://www.osm-3d.org/, accessed 30 July 2017

The font type, colour and halo-radius used for the labels on the "OSM-WMS worldwide" base map are not very appropriate. It influences the places' names readability and map harmony (Figure 2.22).

Fourth zoom level

Ninth zoom level

Figure 2.22. *Labels on the "OSM-WMS worldwide" base map*

At smaller-scale zoom levels improper place labelling was used, country names are visualized with lower importance than city names. Also bad visibility of administrative boundaries between countries in Europe, which are hidden under the road network, because of its intensive colours.

On middle-scale zoom levels, the detalization of generalization for railways and secondary roads is too high, and also line width appropriated to them is too wide. The hierarchy of visualized objects is unbalanced on middle-scale zoom levels. Also names of some big cities are missing, e.g. London, Budapest.

At larger-scale zoom levels, the map is overloaded with map features. The map also contains outdated information, e.g. Yugoslavia. There are overlaps between map features, and object names are sometimes illegible.

Generally, the map design is old-fashioned. Map as well as the project, require some improvements and refinements since the last modification was committed in May 2012 (according to the News section).

5. OldMapsOnline.org[53]**.** This project is identified as a searching engine for historical maps. It was created by the Great Britain Historical GIS Project based at the University of Portsmouth, UK and Klokan Technologies GmbH, Switzerland (Přidal & Žabička, 2008).

[53] http://www.oldmapsonline.org/, accessed 31 August 2017

The project includes over 400.000 maps, collected from participating institutions archives and libraries which were open to the project idea and provided their online content.

When pressing "Browse the old maps", the user is transferred to a new window, as demonstrated in figure 2.23.

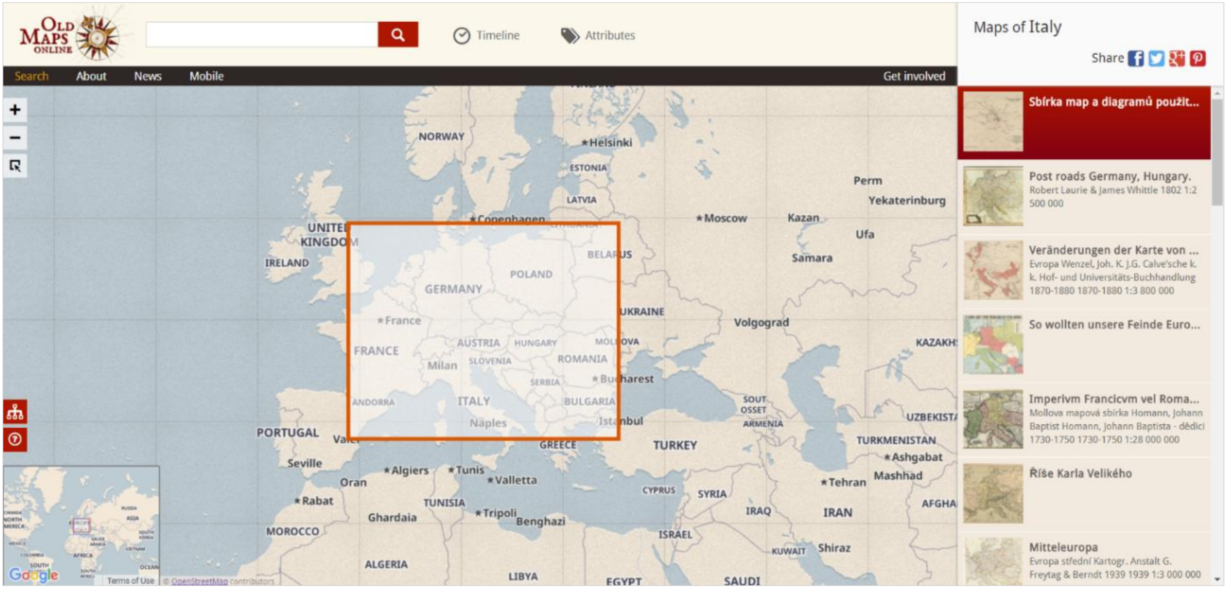


Figure 2.23. *The working window of the OldMapsOnline.org project*

In the middle of the map, there is a bounding box, that defines an area for which service will automatically propose a list with possible online historical map images, on the right side, provided by multiple sources, i.e. host institutions. Moreover, service includes a search box, timeline filter, attributes setting filter, zoom in/out buttons, exact area tool, area analyser button, help toolbar, and a small navigation window with Google Maps.

Since the background map is used for orientation and supportive purposes, the map itself is implemented in simplified and explicit styles which leads to a high readability level. In general, the map has 18 zoom levels. At small-scale zoom levels, the map includes besides land and hydrography, continent names, country names, several capitals, big cities names, and the administrative boundaries of countries. On middle-scale zoom levels, additional map features are visualized, such as states, districts or provinces administrative boundaries, roads, vegetation areas, additional cities and settlement places. At the larger-scale zoom levels, the list with visualized features is extended: railways, land categories, street names, some categories of POIs, and building. Figure 2.24 shows examples for different zoom levels.

Figure 2.24. *Examples of the base map at small-, middle- and large-scale zoom levels*

To sum up, the base map design is advanced and sophisticated. The visualized OSM data looks harmonized, pleasant and well readable. The map is highly suggested for localization, orientation and thematic support purposes.

6. OpenMapSurfer[54] is another project performed by the group of researchers from the Chair of GIScience, Heidelberg University, Germany in 2011. The tiled web map service with a world coverage is generated with a usage of OSM data and several other sources. It was released under CC BY-SA 2.0 license.

Figure 2.25. *The home page of OpenMapSurfer*

In this project MapSurfer.NET Framework was applied as a rendering map engine. The use of multiple data sources gives the map a more advanced transition between zoom levels. At a certain range of zoom levels, additional data sources are visualized together with OSM data. Examples for small-, middle-, and large-scale zoom levels are demonstrated in figure 2.26.

[54] http://korona.geog.uni-heidelberg.de/, accessed 31 August 2017

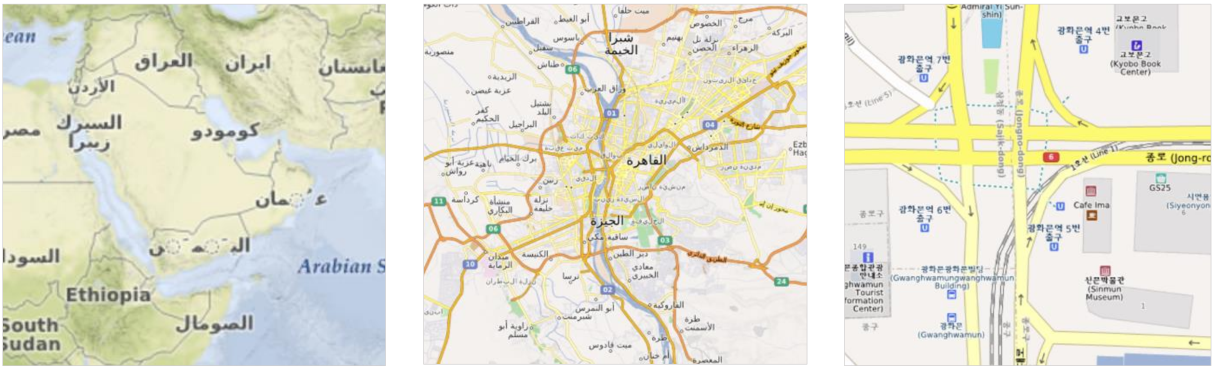


Figure 2.26. *Fragments of the base map of OpenMapSurfer for small-, middle- and large-scale zoom levels*

Additionally, there is an option for the user to switch between six base map types and additionally apply four overlays.

Many other tiled web map services and tiled map styles exist, for instance, já map[55], eniro map[56], Mapy.cz[57], Baidu map[58], some can be found through this link[59], and many others are not mentioned in this section, because of time frame reasons. However, the given examples helped to derive some guidelines for base map visualization, and understand the development stages of tiled web map services, and moreover provided with inspiration for the design and styling of the prototype base map.

2.3.2. Aspects of multi-scale base map design

The design of a multi-scale base map for tiled web map services, is a broad subject, due to the factors elicited by its application domain, user requirements, and the context of particular usage (Poppe & van Elzakker, 2006).

It was indicated by Foerster *et al.* in their scientific paper, that an adequate base map information is unavailable for appropriate communication of the thematic content (Foerster et al., 2012). Therefore, to be able to achieve sufficient cartographic communication and fulfil intended users' requirements (preferences), there is a necessity for cartographers to take into consideration certain aspects in multi-scale base map creation and design (Muehlenhaus, 2014). In this Master Thesis, the author considers following aspects: *content, zoom levels, generalization, and symbolization*.

[55] https://en.ja.is/kort/?type=map, accessed 31 August 2017

[56] https://kartor.eniro.se/, accessed 31 August 2017

[57] https://mapy.cz/, accessed 31 August 2017

[58] http://map.baidu.com/, accessed 31 August 2017

[59] http://wiki.openstreetmap.org/wiki/Tiles, accessed 31 August 2017

In the same scientific paper by Foerster *et al.*, two requirements for the base map were discussed. The first requirement is about the state of the initial topological consistency between the background and foreground maps, which is derived from user preferences. This topological relationship assists the user with a linking the map to the real world. The second requirement is obtained from the user profile. It includes specific information needs about the thematic map, and therefore a base map should be adjusted to them. This means that the user should get an enhanced base map with emphasized thematic content in it. The article provided two consequences for the second requirement. First it says, that two different users can have two different base maps for the same thematic scope and secondly, that different objects from the same class can be visualized on different zoom levels (Foerster et al., 2012).

Content. Typically a base map is intended to provide a communication between geographic context and the thematic data, therefore base maps require appropriate minimalism and simplicity (Muehlenhaus, 2014). Too much information may confuse the users. Therefore map elements should be included or excluded driven by two principles: the purpose of the map and the probable map audience (Muehlenhaus, 2014).

It is important to define base map specifications which describe the information content of the base map. It involves the spatial extent, the geographic concepts represented, scale range, and the overall level of detail (Balley et al., 2014).

Foerster *et al.* reasoned, that the user profile may specify the user requirements about the base map related to a specific use of the thematic content. Therefore, to fulfil user requirements it might be essential to customize the topographic data. Moreover, properly selected base map objects play a crucial role for a base map which should not affect the thematic content or distract the user with unnecessary content (Foerster et al., 2012).

Zoom levels. As was described before, the tiled web map is constructed with a certain amount of zoom levels, also known as level of detail (LOD). Each of those zoom levels is represented by a static base map, constructed from tiles. Therefore, in total, the web map can usually have around 20 static base maps, generated for each zoom level accordingly (Muehlenhaus, 2014; D. A. Smith, 2016). In this context LOD plays an important role in increasing the mapping speed and reducing map production workload through the all map scales (Brewer & Buttenfield, 2007, 2010).

Muehlenhaus in his book demonstrated, that the web map can be '*unintelligible*', due to a number of zoom levels available for users. Therefore, each zoom level should be assured and approved by the information significance and usefulness which must be given to that particular LOD (Muehlenhaus, 2014). The author also provides a description of three interactive techniques, e.g. panning, zooming, and map rotation, which is beneficial in sense of slippy maps. For zooming, author provides a suggestion, where the a number of zooms must be limited. It will let the user feel the map interactivity and on the other side to perceive the map message and content (Muehlenhaus, 2014). Furthermore, the number of zoom levels increases the hosting demand for pre-rendered tiles (D. A. Smith, 2016).

Generalization. Generalization is aiming at improving map display at small-scale zoom levels by virtue of simplification and clarification of map features, and stressing the crucial meaningful information based on specific purposes and users' needs (Foerster et al., 2012; Hardy & Watkins, 2012; Poppe & van Elzakker, 2006). Generalization is the process of reducing the amount of data and adjusting the information to ensure a legible and aesthetically pleasing result on all zoom levels (García et al., 2012; Schmidt & Weiser, 2012).

Generalization could significantly improve the quality of multi-scale base map display, and automation is needed to achieve efficient generation of tiles (Schmidt & Jörg, 2012). Therefore, generalization plays a key role in the process of adjusting the features to the particular zoom level. All zoom levels require a careful selection of features, appropriate symbolization, and smoothing.

For instance, in the Basemap.at project, data harmonization and generalization were the main cartographic challenges in producing the multi-scale base maps (Schmidt & Weiser, 2012).

More about generalization for on-demand maps can be found in a dissertation of Foerster on a topic "Web-based Architecture for On-demand Maps – Integrating Meaningful Generalization Processing" (Foerster, 2010).

Symbolization. Symbolization plays an important role in web map communication. Rarely the default web map symbols sufficiently portray the information they are visualizing in an intuitive manner. Therefore, effective visual communication requires intuitive symbolization (Muehlenhaus, 2014).

Muehlenhaus in his book provides some core aspects for symbolization, namely: keep symbols simple, generic caricatures are best, and symbols are a period, audience, and context dependent (Muehlenhaus, 2014).

It is understandable, that there are much more factors that influence on base map efficiency, harmonization, and pleasantness. For instance, a colour scheme which is an significant step in powerful and useful map design (Muehlenhaus, 2014). Also typography, visual variables and many others.

For tile mapping it is also essential to consider high-density pixel displays, the higher the screen's pixels per inch is, the smaller the tiles will look. It also concerns labels on the tiles, which can shrink with the tiles and often are illegible (Muehlenhaus, 2014).

There is also an important factor as anti-aliasing which is performed by adding lighter pixels around sharp edges to soften the stair-step effect (Peterson, 2012b).

2.4. Conclusion

In this chapter, the fundamental theory behind tiled web map services, its tile numbering schemes, and standards was illuminated. Besides already known raster tiled map systems, a part of this section was dedicated to the vector tiled map systems, its standards, approaches, advantages, and disadvantages.

In one of the theoretical sub-sections, the overview of most important usability studies with the stress on the web map design guidelines, conducted by other researches in a period from 2008 until 2014, was performed.

Moreover, the development of the multi-scale base map in the web mapping environment was represented. The base map is commonly used in GIS software, as a background topographic layer which can be overplayed with thematic content, produced by the user.

This section also examined related work and examples in multi-scale base map design completed by commercial and non-commercial institutions. Finally, aspects of a multi-scale base map design were emphasized, i.e. content, zoom levels, generalization, and symbolization. These aspects are also considered in methodological approach.

3. Methodology

This chapter explains the chosen methodologies used to achieve the practical results and offers an answer to the first research question. It includes a critical review of the base map of existing tiled web map services. Moreover, it explains in the detail the usage of OpenStreetMap data in the context of tiled web maps.

3.1. Multi-scale base map review

For this research, it is important to evaluate base maps provided by well-known web mapping services such as Google Maps, Yandex Maps, Bing Maps, MapQuest, HERE WeGo, and OpenStreetMap. Each base map is critically analysed and described for purposes of making decisions in the design and implementation of the base map for the tile-based web map application.

The base maps provided by MapBox are not evaluated here. Nevertheless, MapBox base maps are discussed before in related work (Section 2.3.1). Furthermore, base maps provided by MAPS.ME[60] and Apple Maps[61] are also not assessed, due to their availability only for mobile and tablet platforms, and another system vendor, i.e. macOS.

It is difficult to objectively assess the quality of web map design, i.e. graphical attractiveness, clarity and efficiency (Jenny et al., 2008). This review is focusing on the cartographic criteria: content, symbolization, scale level transition, generalization, performance, and harmonization. The functionality of web maps is not considered.

In addition, at the end of the review section, table 3.1 provides common issues, that often appeared in the majority of web maps.

3.1.1. Google Maps

Google Maps is a leading provider in web map service industry (BuiltWith, 2017). Service includes a wide spectre of tools and functions which are available for users. Moreover, company developers and designers regularly apply changes for improvement. However, this service contains certain issues which the author finds important to mention.

60 http://maps.me/en/home, accessed 30 August 2017

61 https://www.apple.com/ios/maps/, accessed 30 August 2017

First of all, it is necessary to adjust and modify language packages and versions for different countries. It is suggested to control and manage a number of languages used for visualizing countries' names, demonyms.

Figure 3.1. *Switzerland demonyms*

Figure 3.2. *Bosnia and Herzegovina demonyms*

Otherwise, it could lead to overcrowded maps. At middle-scale zoom levels, it also hides the map content (Figure 3.1 and Figure 3.2).

On all zoom levels, white gaps between tiles or background grid are visible, especially when dragging on the map within sea areas, there is a flicker effect, which changes the white colour intense value.

At small-scale zoom levels, it is suggested to label districts', provinces' or states' names for some large countries, e.g. China, Russia, Mongolia, Kazakhstan, India, and Argentina. Sometimes the map is also overcrowded with the amount of motorways, e.g. Cologne and Shanghai areas.

At middle-scale zoom levels, primary roads that go through forests are difficult noticeable. The density of visualized secondary, tertiary, residential, or service roads is enormous. Moreover, the visualized amount of public railways is dense.

At large-scale zoom levels, the road labelling on tiny areas is too dense, examples are demonstrated in figure 3.3.

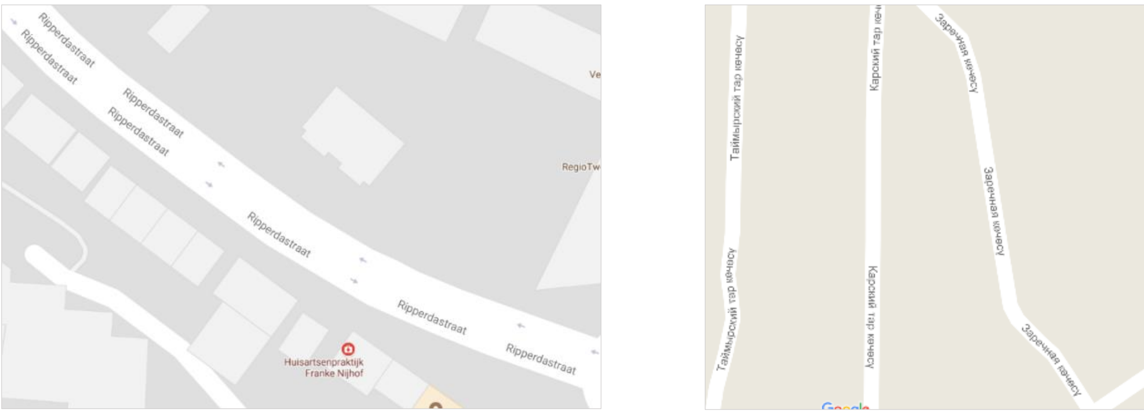


Figure 3.3. *Roads labelling issues*

Railways are not visible. Sometimes buildings cover roads and paths. Symbols of train and bus stations are distinguishable with some difficulties. A number of direction arrows on tertiary, residential, or service roads are too big.

From time to time, some important places, e.g. airports, are not represented on the map. The sequence of cities appearances within transition levels is not always consistent, secondary cities can appear before the capital city.

3.1.2. Yandex Maps

Yandex Maps is a web mapping service developed by Yandex. It provides a web map, that covers the whole world. The author's opinion is that the quality of map itself is not satisfactory.

At small-scale zoom levels, river visualization is only applied to selective countries, e.g. Egypt, Russia, China etc. It is suggested to apply it also to countries that have sufficient areas with rivers, e.g. USA, Brazil, Australia, Canada, Algeria, Argentina etc. Atlantic Ocean label is placed improperly, only in the area close to Boston City in the USA.

As demonstrated on figure 3.4, there is a big issue with illegally appropriated territories that have not been recognized on the international level, they are included in other countries or visualized as independent states, e.g. Crimea, Jammu and Kashmir, Abkhazia, South Ossetia etc.

Figure 3.4. *Examples of illegally appropriated territories*

At small-scale zoom levels, there is a discrepancy in the placement of cities' names for certain countries. The number of visualized cities for Afghanistan is much bigger in comparison to Algeria, Libya etc. which occupy significant areas.

There is inconsistency in visualizing the priority between cities' and countries' names for moderate size countries, e.g. Slovakia, Brunei, Czech Republic etc.

The transition between fourth and fifth zoom levels in visualising some large water areas, e.g. Lake Victoria, is too abrupt. Moreover, administrative boundaries between countries and their districts passing through hydrographic objects are insufficiently visualized and some water objects were named inappropriately, "ozero Mai-Ndombe" should be "lake Mai-Ndombe".

At middle-scale zoom levels the names of some cities are not correct, e.g. Bangalore is now Bengaluru, Kyiv is Kiev, Mangalore is Mangaluru and other.

At large-scale zoom levels, there are big issues with street labelling, font sizes, object placement rules and generalization algorithm which makes the map too cluttered and overloaded and map elements are overlapping (Figure 3.5).

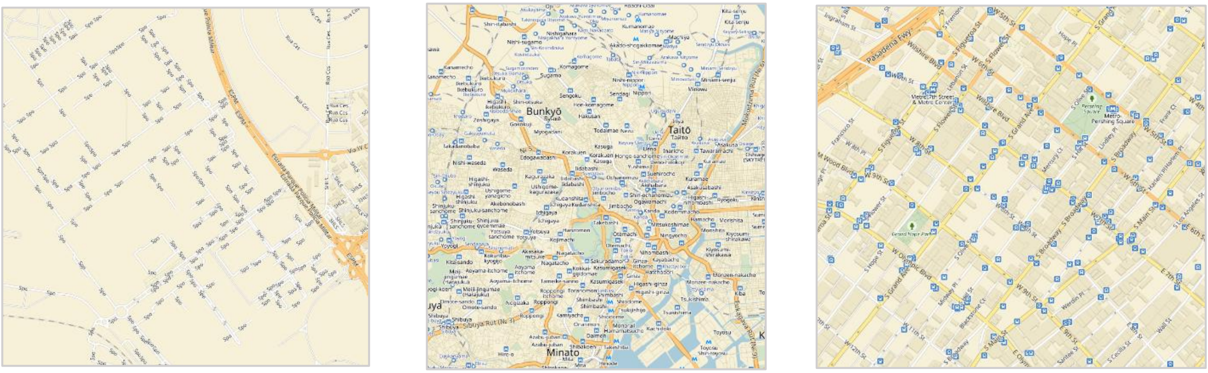


Figure 3.5. *Issues in generalization and labelling algorithms*

Additionally, the visualization of megalopolises, for instance, Delhi, Seoul, Brasilia etc. is poor and wretched.

3.1.3. Bing Maps

Microsoft's web mapping service, Bing Maps which uses HERE as part of its mapping system, does not include map coordinates of the screen centre and zoom level for the visualized region in its URL.

At the initial zoom level only a few countries, e.g. Canada, USA, Australia have twice bigger country name font sizes, than other countries, e.g. France, Algeria, Argentina, Kazakhstan, Ukraine, Turkey, Sudan, India, Libya, Mexico, Iran etc.

At small-scale zoom levels some country capital names are missing, e.g. Madrid, Quito. The density of motorways is too detailed, for instance, the Netherlands, Germany, and New Delhi areas. Also, the secondary, tertiary or residential roads are too dense, example of the England area. See figure 3.6.

Figure 3.6. *Issues with the density of visualized roads*

At middle-scale zoom levels it is sometimes problematic to follow the changes of a certain map object, because of the sharp transition. Also, the visibility of roads passing over water objects is poor. Furthermore, the density of primary roads within some areas is quite high.

At large-scale zoom levels, train stations include several icons that correspond to only one train station feature itself (Figure 3.7). Moreover, too many public transport stops are visualized for some localities (Figure 3.8).

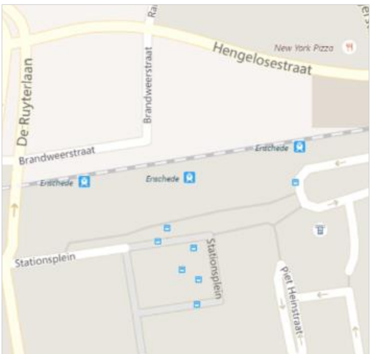


Figure 3.7. *Issue with the number of icons for one train station*

Figure 3.8. *Issue with the number of transport stations*

Tram stops and train lines for some cities, as a part of public transportation network, are missing, e.g. Vienna, Austria; Lviv, Ukraine; Warsaw, Poland; Munich, Germany; etc.

Furthermore, the generalization applied for rivers at small- and middle-scale zoom levels is poor.

Some of the location names are outdated, based on the examples of Ukrainian cities: Kirovograd was recently changed into Kropyvnytskyi, Dnipropetrovsk was altered into Dnipro, and Nikolayev in Lviv District should be renamed to Mykolayiv, according to the official transliterated name.

3.1.4. MapQuest

As well as Bing Maps, the MapQuest main URL does not contain map coordinates of the screen centre and zoom level for the visualized region.

At the smallest-scale zoom level, the visualizing of districts, states, and provinces for countries is not beneficial, e.g. people who are new to web maps can be confused with such divisions. Country boundaries are not emphasized appropriately on the second zoom level. The map fragments in figure 3.9 show that it is difficult to distinguish districts from country boundaries.

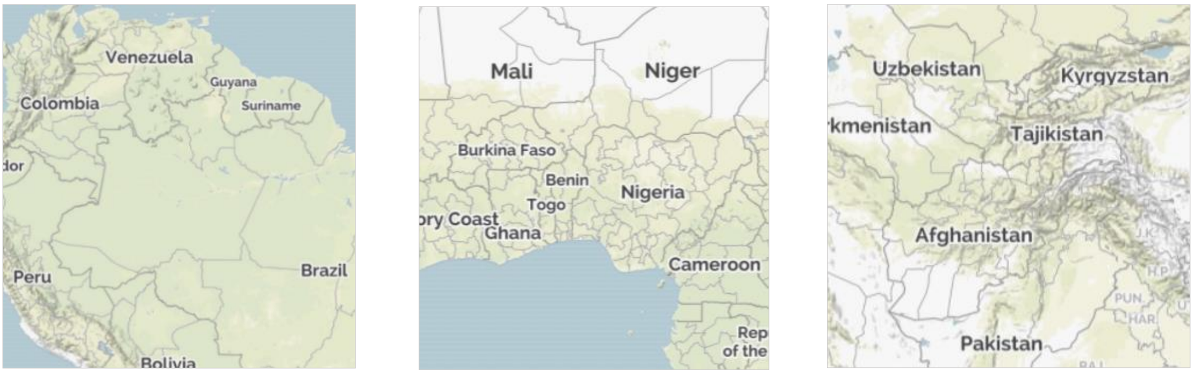


Figure 3.9. *Issues with districts' boundaries and countries borders*

At the small-scale zoom levels, some of Latin America countries' names were placed too tightly, e.g. Honduras, El Salvador, Guatemala etc. On the other side, not all capital cities are visualized for some countries, like North Korea, Pakistan, Czech Republic, Bangladesh, Hungary etc. Furthermore, compared to USA and Mexico some large countries' areas look empty because of low amount of visualized cities, e.g. Germany, Poland etc.

At middle-scale zoom levels it is a bit difficult to find and read place names that are located in mountains areas. Capital cities' names are visualized with different font size values. There is also a language issue, when several languages are applied for cities' names on the territory of one country, e.g. Russia and Kazakhstan.

At large-scale zoom levels, railways are not truly noticeable. Parks' or green areas' symbols are placed on the top of buildings polygons, which are surrounded by green areas. Building labels are placed inappropriately. Furthermore, the map fragments in figure 3.10 show that bicycle paths are not really distinguishable from footpaths.

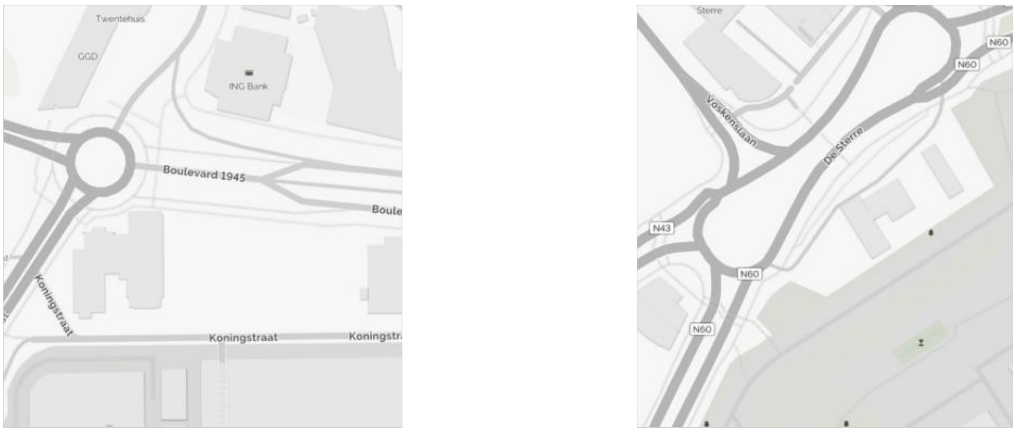


Figure 3.10. *Issues with visualizing bicycle paths*

At the largest-scale zoom level, streets' names and labels are repeating too frequently on a short street distance. It is suggested to modify street labelling rules and algorithms. It is also not appropriate to visualize only a part of POIs when there are much more POIs exist in that particular area.

To sum up, the map service looks too commercial because of the predominance of a single hotel searching platform that belongs to one company. Too many buttons and tools that relate to the hotel service are embedded.

3.1.5. HERE WeGo

HERE WeGo was formerly known as HERE Maps a web mapping service developed by HERE company that provides mapping data and related services.

At the smallest-scale zoom level showing continent labels is beneficial, nevertheless visualizing of the continent without borders does not make any sense for users who are new to web maps and Geography, i.e. pupils or children.

At the small-scale zoom levels, the number of motorways in some areas is too dense. Moreover, the difference in colour between motorways and main roads is poor, which at some point, especially when there is a dense road network, makes it a bit problematical to differentiate between these road types, see figure 3.11.

Figure 3.11. *Issues with roads' symbolization and generalization*

Furthermore, there are too many secondary cities visualized for certain countries, e.g. India, Indonesia, Mexico, and Iran. The big amount of secondary cities suppress the capital city, e.g. Mexico City, Washington, also font sizes are incorrectly applied, e.g. Canberra font size is smaller than Adelaide.

At small-scale zoom levels, it is suggested to include abbreviations or full names of districts, provinces or states of large-area countries instead of the secondary cities, i.e. for China, Kazakhstan, Mongolia, Algeria, Saudi Arabia etc. as applied to the USA, Russia or Canada.

At the middle-scale zoom levels, some big vegetation areas are missing which makes the land a bit empty, e.g. national parks in Iran, Pakistan, Egypt, Afghanistan, Tajikistan etc. It is suggested to visualize cities for all countries more uniformly, to avoid countries with dense and sparse amount of visualized cities, e.g. India versus Kazakhstan. The transition between the eighth- and ninth-scale zoom levels for vegetation polygons is too sharp.

At the large-scale zoom levels, the symbolization of the transportation network, especially for big cities is insufficient. The examples in figure 3.12 show the following issues: too many stations' symbols are visualized, transport stations look complicated, stations are not signed clearly, labelled properly, as well as placed correctly.

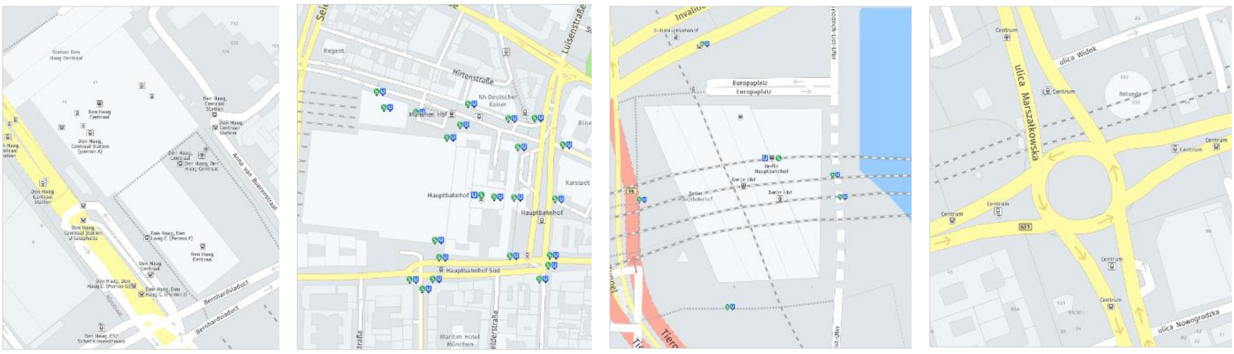


Figure 3.12. *Issues with transport stations symbolization and labelling*

Visualization of some megalopolises at large-scale zoom levels, for instance, Tokyo, Shanghai, Seoul, Beijing, Kabul etc. is poor. Moreover, roads or paths are sometimes hardly cover building structures. Occasionally, the railway network is insufficiently visualized. Streets' names and labels are repeated too frequently on short street distances and small areas. It is also suggested to improve the address labelling scheme with building numbers.

3.1.6. OpenStreetMap

OSM is the best-known example in collaborative mapping, where the web map service was created from VGI, provided by contributors (Bennett, 2010).

The map is implemented using a multi-language approach. It is highly suggested to make the map more international.

At the smallest-scale zoom level, the map coverage looks poor. As demonstrated in figure 3.13, the visualization of districts, provinces or states for small countries, e.g. Moldova, Uganda, Georgia etc., leads to overcrowding with lines inside the country territory.

Figure 3.13. *Issue with visualization of districts, provinces or states*

For the territory of China at small-scale zoom levels, it is suggested to reduce the amount of visualized cities. The map fragments in figure 3.14 show that the number of motorways in some areas is too dense. Moreover, the difference in colours between motorways and main roads is poor which at some point, especially when there is a dense road network, makes it a bit difficult to differentiate between these road types.

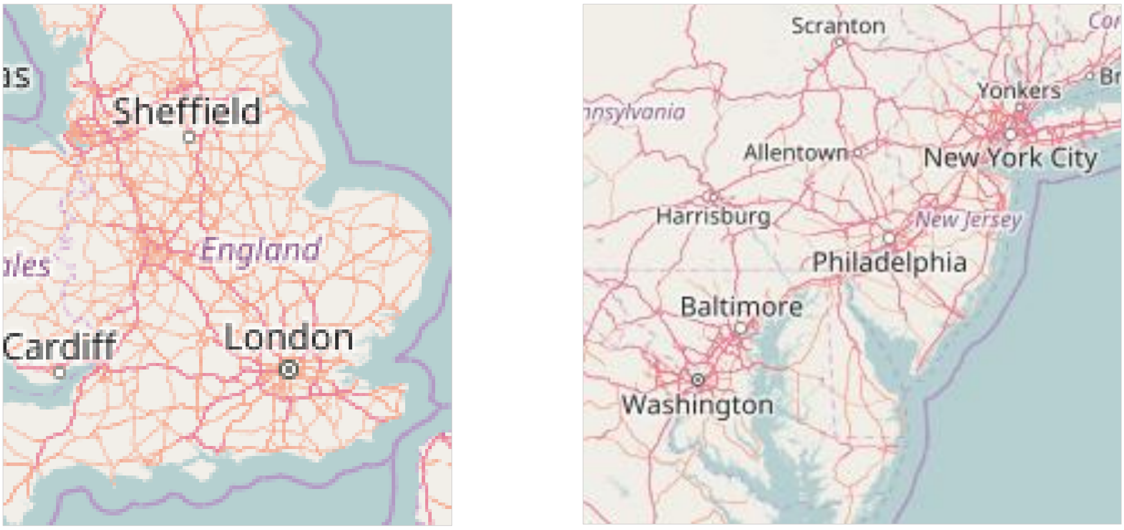


Figure 3.14. *Issue with the density of visualized motorways and primary roads*

The transition between certain-scale zoom levels is too sharp. It significantly enlarges a number of map features on a new zoom level and at some point, it is problematic to follow the changes of a certain map object.

At the middle-scale zoom levels, the density of the primary and secondary roads is too high. The street names and labels are repeating too frequently on a short street distance. The amount of POIs is too dense. Railways are visually more dominant than other connections, i.e. roads. Moreover, the visibility of platforms' numbers is unclear.

3.1.7. Common issues

The most common issues of the reviewed web mapping services are described in table 3.1. The issues are presented in descending manner, from frequently to rarely repeated. Single issues are not considered.

Issue	Details
Density of motorways and primary roads	At small-scale zoom levels, the amount of visualized motorways and primary roads is too large.
Road labelling	The map at large-scale zoom levels looks too cluttered because of too dense road labelling.
Districts', provinces' or states' names for some large countries	At small-scale zoom levels, districts', provinces' or states' names for some large area countries are missing which makes map not harmonized and disproportional with respect to the amount of visualized data in different areas.
Amount of visualized cities	The map looks unbalanced because of the different amount of cities which are visualized for different countries.
Language	The map does not obey one language package or the amount of used languages is too big.
Density of secondary, tertiary, residential, or service roads	At middle-scale zoom levels, the number of visualized secondary, tertiary, residential, or service roads is enormous.
Transition	It is problematic to follow the changes of a certain map object because of the sharp transition between zoom levels.
Sequence of data appearance	Visualized data sometimes do not follow logical rules or personal expectations.
Data is not up-to-date and some objects are missing	Some maps do not provide actual data which is up-to-date.
Megalopolises or giant cities visualization	At large-scale zoom levels, some megalopolises and giant cities are visualized inefficiently.

Table 3.1. *Common issues of web map services' base maps*

3.2. The use of OpenStreetMap data

At the earliest stages of accessing the tiled web map services many web mapping providers eluded OpenStreetMap (OSM) or any other open source data usage, because of unclearness with license terms and quality of the data (Schmidt & Weiser, 2012; Zhang & Malczewski, 2017). On the other hand, due to the lack of free and open geographical information sources which provide an alternative to authoritative and commercial geodata (Behrens, van Elzakker, & Schmidt, 2015; Fast & Rinner, 2014), and ability for users to collect data themselves with Global Positioning System (GPS) and share it through the web (Bennett, 2010; Mitchell, 2005; Zhang & Malczewski, 2017), a new plateau of crowd-sourced content production was opened, more known as Volunteered Geographic Information (VGI) domain (Goetz, Lauer, & Auer, 2012). Collaborative and open data is one of the trends that has emerged within last decade (Grīnfelde, 2016).

The open data progress was integral to the arrival of an extensive variety of public division datasets for free in standardized and shareable form (Kitchin, 2014; Neumann, 2012; Schlesinger, 2015; D. A. Smith, 2016). The most common data sources are a blend of private data providers, administrational data and VGI (Schmidt & Jörg, 2012).

Some studies showed that OSM data quality in comparison to commercial data providers has a tiny difference (Haklay, 2010; Zhang & Malczewski, 2017), which means that OSM data is competitive. Moreover, many commercial organizations and governmental bodies have started to contribute to OSM (Bennett, 2010). Subsequently, big online map providers, such as Bing Maps and MapQuest in 2010 switched to OSM data usage as a source for base maps (Schmidt & Weiser, 2012), moreover MapBox also uses OSM data (D. A. Smith, 2016). OSM has become one of the most popular resources for map production (Behrens et al., 2015).

3.3. Conclusion

In this chapter, the basic methodologies which are used in this thesis were emphasized. A critical review of the base maps of existing tiled web map services was performed with the purpose to analyse cartographic issues, to comprehend and adhere aspects in the design of the best-known and frequently used base maps on the web. Moreover, the most common issues were also emphasized. In the end, OpenStreetMap data was briefly discussed as an open-source and commonly used data for multi-scale base map creation.

4. Implementation

This chapter explains the techniques used to implement a tile-based web map application and offers an answer to the second research question. It focuses on the design of multi-scale base maps and the applied workflow to build a tile-based web map application.

Moreover, this chapter considers a background of the survey of a group of users of tiled web map services, that was conducted in August-September 2017 in order to evaluate the created styles for the tile-based web map application.

4.1. Design of the multi-scale base maps

The design of a multi-scale base map was initiated by its usage purposes, that are localization and orientation, and thematic support. In general, three styles for a base map are developed, namely *Original, Light,* and *Dark*. Styles are produced for 18 zoom levels, however the area of Luxembourg is visible in detail, starting from the ninth zoom level.

The *Original* style is implemented mainly for localization and orientation purposes. The main idea of this style is to visualize base map objects in a harmony and balance, therefore the dominance of certain map features was reduced with colours from a tranquil palette. Fragments of the base maps at small-, middle-, and large-scale zoom levels are demonstrated in figure 4.1.

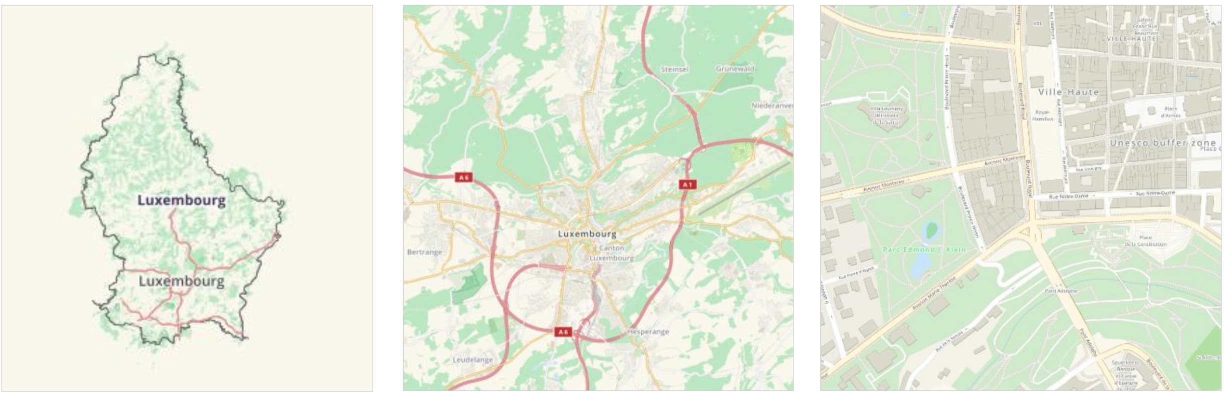


Figure 4.1. *Examples of Original Style at small-, middle-, and large-scale zoom levels*

Light and *Dark* styles are implemented for the purpose of thematic support. The main gist of these styles is to visually emphasize vegetation, and hydrographic objects. The difference between *Light* and *Dark* styles lies in the application of colours from opposite palettes, light and dark accordingly.

The *Light* style is implemented with light colours. Such configuration may lead to better overlaying with dark thematic layers. Fragments of the base map at small-, middle-, and large-scale zoom levels are demonstrated in figure 4.2.

Figure 4.2. *Examples of Light Style at small-, middle-, and large-scale zoom levels*

The *Dark* style was implemented with using dark colours. Such configuration may lead to better overlaying with light thematic layers. Fragments of the base on small-, middle-, and large-scale zoom levels are demonstrated in figure 4.3.

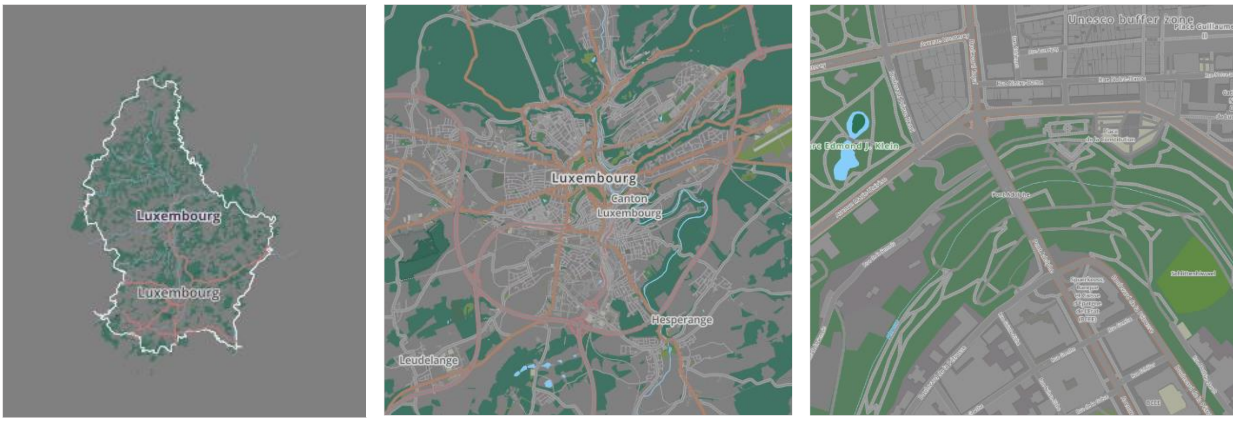


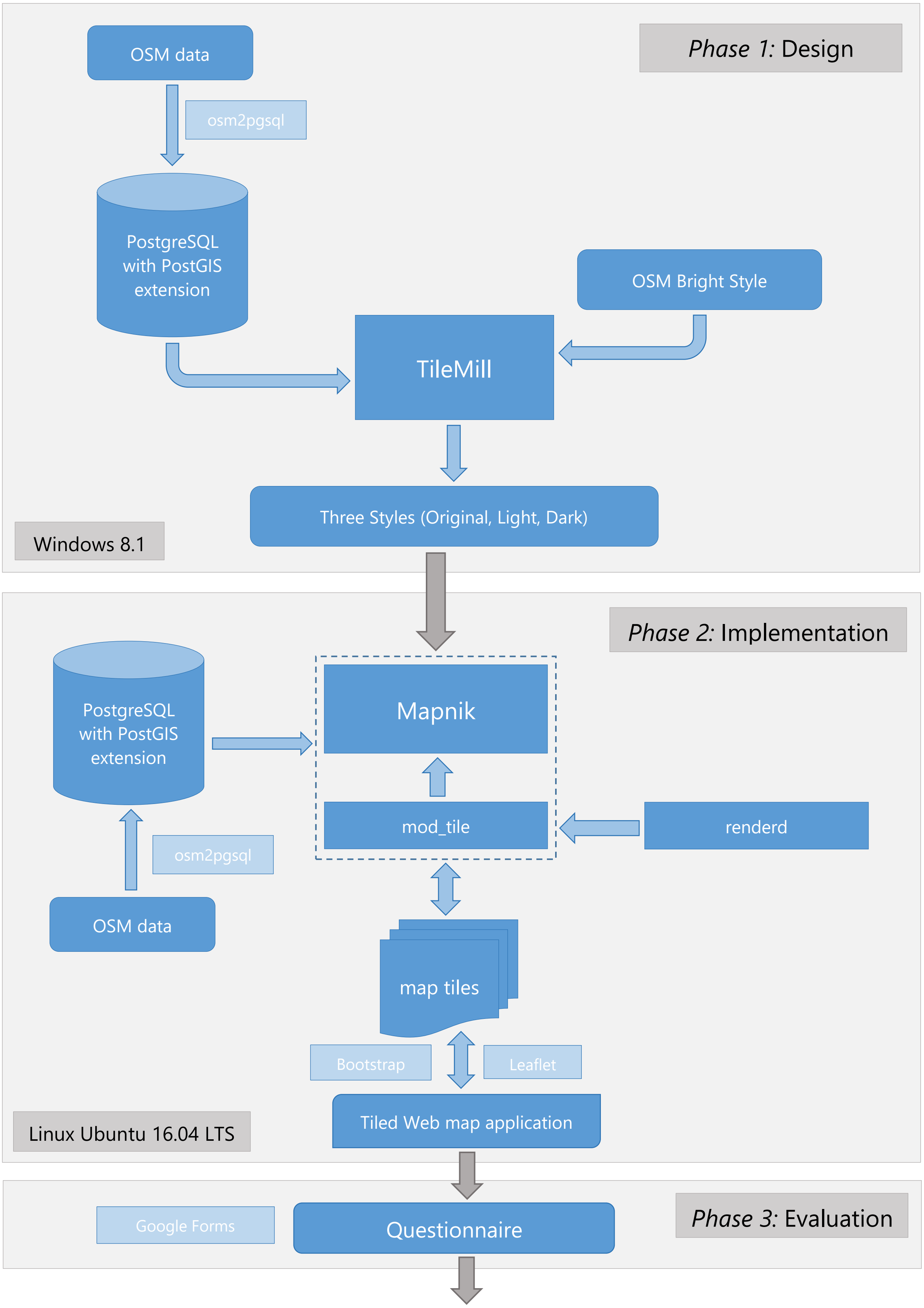
Figure 4.3. *Examples of Dark Style at small-, middle-, and large-scale zoom levels*

For each map type a design concept was created: defining styles, selection and generalization rules for each zoom level. The design is also following the guidelines provided by the ScaleMaster diagram[62], developed by Cynthia Brewer. ScaleMaster is a structured diagram for organizing multi-scale mapping using design, selection, and generalization decisions (Brewer & Buttenfield, 2007, 2010). The diagram helps to understand and follow the cartographic data model requirements (Schmidt & Weiser, 2012). The created base maps also follow the stepped guidelines in the design of the web maps provided by Muehlenhaus in his book (Muehlenhaus, 2014). It includes five-step process to design effective layouts, namely: 1) identifying the web map audience and its expectations; 2) determining which kind of web map will be designed; 3) identifying which elements of the visual hierarchy need to be prominent; 4) creating trial layouts and user test; and 5) finalizing the map layout and conducting a user test (Muehlenhaus, 2014).

[62] http://personal.psu.edu/cab38/ScaleMaster/, accessed 31 August 2017

4.2. Workflow

The workflow procedure from the stage of data retrieving till launching of the tiled web map application is described and schematically visualized in figure 4.4. The workflow is divided into four phases: Design, Implementation, Evaluation and Alteration.



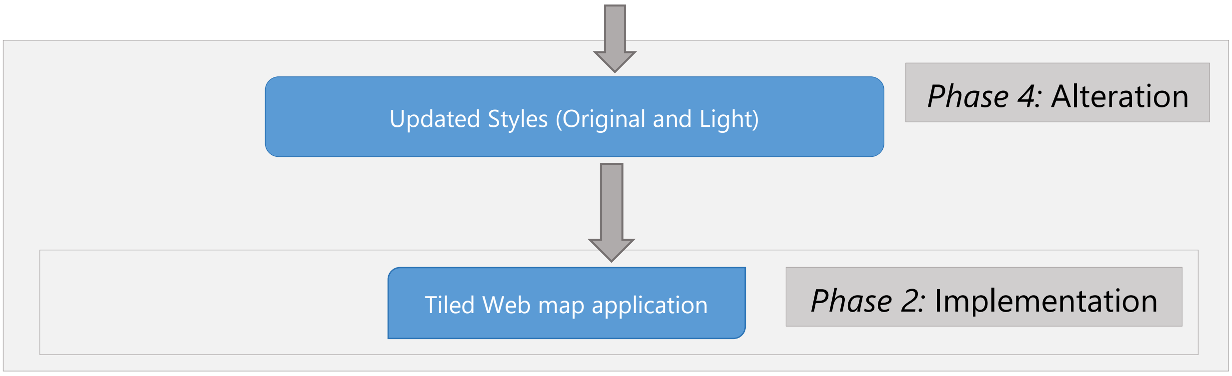


Figure 4.4. *Workflow architecture*

Phase 1 – "Design". The aim of this stage is to design map styles, that will be applied to the tiled multi-scale base map. This phase is accomplished on Windows OS.

- Input: OSM data, retrieved from Geofabrik[63], for the area of Luxembourg in "luxembourg-latest.osm.pbf" file format. OSM Bright style[64], cloned from GitHub repository.
- Output: Three styles (Original, Light, and Dark) in XML format were produced.

Phase 2 – "Implementation". The target of this phase is to generate tiles with customized styles and set up a tiled web map application which can be accessed online. This phase is performed on Linux Ubuntu OS.

- Input: OSM data for the area of Luxembourg in "luxembourg-latest.osm.pbf" file format. Three styles (Original, Light, and Dark) in XML format.
- Output: Tiled web map application.

Phase 3 – "Evaluation". The main goal of this phase is to evaluate created map styles through the questionnaire.

- Input: Tiled web map application.
- Output: Feedback from questionnaire participants about map styles.

Phase 4 – "Alteration". This phase is aiming at the modification of originally created map styles based on the questionnaire results.

- Input: Analysed and summarized feedback from questionnaire participants about map styles.
- Output: Updated map styles and modified tiled web map application.

[63] https://www.geofabrik.de/data/download.html, accessed 31 August 2017
[64] https://github.com/mapbox/osm-bright, accessed 31 August 2017

4.2.1. OSM Bright styles

Created base map styles are modifications of OSM Bright style, produced by MapBox. OSM Bright style was implemented in CartoCSS, the syntax language based on long-established web standard - CSS, that enables to customize the style of map data (CARTO, 2017). This language provides and easy-to-use means of controlling the styles because it familiar to many designers and general users, and map styling can be done in detail (Muehlenhaus, 2014; D. A. Smith, 2016). Other available CartoCSS projects can be found through on this web page[65].

OSM Bright style was released under the MapBox permissive licence which lets redistribution and its usage in source and binary forms, with or without modification, when certain conditions are met. OSM Bright CartoCSS can be opened as a project in TileMill and applied to the OSM data, stored in several formats.

4.2.2. OSM data preparation

For this project, OSM data was considered as the main data source, because it is available for free, highly standardised, and can be easily retrieved from several OSM data export platforms, inclusive of OSM main page itself (Bennett, 2010). OSM data is licensed under the Open Data Commons Open Database License (ODbL).

Downloaded OSM data was loaded into PostGIS[66]-enabled PostgreSQL database by means of osm2pgsql[67], a command-line based program that converts OSM data to database suitable formats (Goetz et al., 2012). The database usage provides the potential to offer multiple layers or diminish the need for duplicate layers (Clouston & Peterson, 2014). PostGIS is an extension to the PostgreSQL object-relational database, that allows storing, manipulating, and retrieving spatial data (D. A. Smith, 2016; Steiniger & Hunter, 2012). Such database configuration was chosen because of its compatibility with TileMill and Mapnik.

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65 http://wiki.openstreetmap.org/wiki/List_of_CartoCSS_projects, accessed 31 August 2017

66 http://postgis.net/, accessed 31 August 2017

67 https://github.com/openstreetmap/osm2pgsql, accessed 31 August 2017

4.2.3. TileMill and Mapnik

TileMill[68] is an open-source map design environment, developed by MapBox. TileMill is a possible option for generating tiles for subsequent upload (Clouston & Peterson, 2014). In this project TileMill was applied because of embedded GUI which lets the developer dynamically view applied changes to the map styles based on zoom level and other constraints (Muehlenhaus, 2014). TileMill supports variety of input and output formats (Clouston & Peterson, 2014), and it was beneficial for this project. The working window of TileMill is demonstrated in figure 4.5.

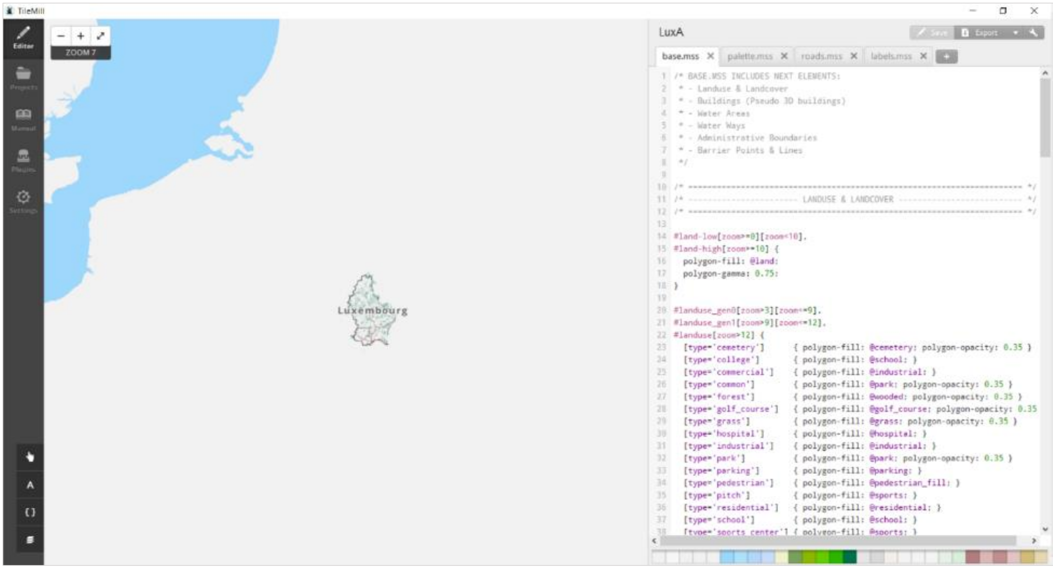


Figure 4.5. *TileMill working window*

TileMill contains Mapnik, a toolkit for building mapping applications (Westra, 2013). Mapnik[69] is a freely-available server-based software library for using geospatial data to render maps (D. A. Smith, 2016; Westra, 2013), released under LGPL license. Mapnik is running on all major OS and implements advanced anti-aliasing and sophisticated style-based map symbology system (D. A. Smith, 2016; Westra, 2013). It also uses a system of XML stylesheets, where symbol rendering orders and label placement are specified via programming symbology rules (Bartoň, 2009; D. A. Smith, 2016).

4.2.4. Leaflet and other web developing tools

To launch the tiled web map service, apart from TileMill and Mapnik, there are several other tools applied. To serve cached tiles and decide which tiles need re-rendering, either because they are not yet cached or because they are outdated, was done with the

[68] https://tilemill-project.github.io/tilemill/, accessed 31 August 2017

[69] http://mapnik.org/, accessed 31 August 2017

implementation of mod_tile[70]. This tool is an Apache module that handles requests for tiles. Apache is one of the most popular web servers (Neumann, 2012). mod_tile allows on-demand tile rendering (Bartoň, 2009).

Another tool was renderd[71], that provides a priority queueing system for rendering requests to manage and smooth out the load from rendering requests (Westra, 2013). Mapnik is the software library that does the actual rendering and is used by renderd. renderd is a daemon that actually renders tiles when mod_tile requests them.

For visualizing created hierarchy of tiles in a web mapping applications a Leaflet[72] tool was used. Leaflet is one of two most popular open-source web mapping Java Script client libraries (Muehlenhaus, 2014; D. A. Smith, 2016) for creating interactive maps.

4.2.5. Architecture

Setting up the tiled web map application was also achieved with a set of general web map design technologies such as HTML, CSS, and Java Script (Dubrava, 2015) and Bootstrap[73] an open-source toolkit for front-end developing.

The figure 4.6 shows the architecture for the a tiled web map application.

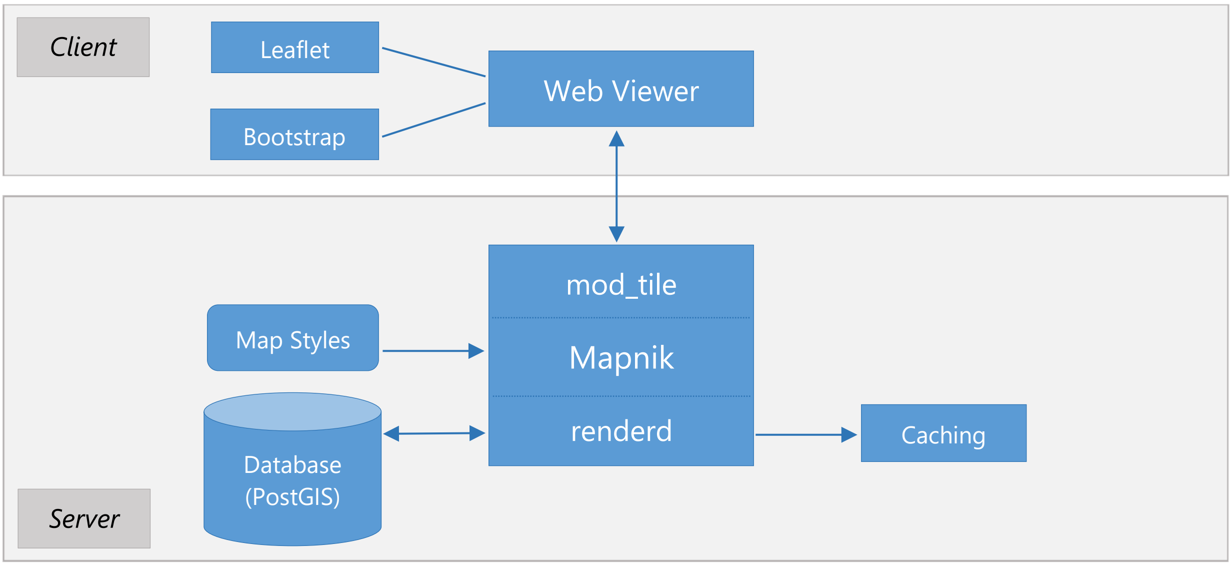


Figure 4.6. *Tiled web map application architecture*

[70] https://github.com/openstreetmap/mod_tile, accessed 31 August 2017

[71] https://github.com/SomeoneElseOSM/mod_tile, accessed 31 August 2017

[72] http://leafletjs.com/, accessed 31 August 2017

[73] http://getbootstrap.com/, accessed 31 August 2017

Nowadays there many tutorials of how to create a tiled web map application, e.g. first tutorial[74] and second tutorial[75]. A tutorial about the OSM rendering process can be found on this web page[76].

4.3. Project questionnaire

One of the research questions is to involve users' wishes and desires into the design of the base map application. To facilitate this, an online questionnaire has been developed to analyse the cartographic quality of a multi-scale base map design.

A questionnaire is an inquiry approach which can be reach a large number of people to get extensive response (Barnum, 2002). A questionnaire was used since it is relatively easy and inexpensive to compile and analyse (Nivala, 2005).

Conduction of the questionnaire was driven by two major reasons:

- Firstly, it was necessary to understand the current state of tiled web map services exploitation among users. Consequently, the questionnaire was used to capture data about users for statistical purposes (Nivala, 2005).
- Secondly, to receive a feedback from participants about created styles for tiled base maps. On the basis of user feedback, it is attainable to evaluate the design against the goals established before (Delikostidis, 2011; Nivala, 2005).

4.3.1. Preparation and conducting

The questionnaire form is provided in Appendix A. In total, the questionnaire contains four open questions and four questions with one or multiple choices.

The questionnaire starts with the introduction part, where the background of tiled base maps and its advantages are given, furthermore the problem of this research is also indicated. Next, the questionnaire is divided into two sections based on driven factors of the survey research.

First section "Usage of a Base Map Service" contains general questions about tiled base maps. In this part the most commonly used tiled web map services are defined, to understand what does the user prefer in tiled base maps, and what are the main purposes of their usage.

[74] https://switch2osm.org/manually-building-a-tile-server-16-04-2-lts/, accessed 31 August 2017
[75] http://blog.davidelner.com/create-map-with-tilemill-and-leaflet/, accessed 31 August 2017
[76] https://ircama.github.io/osm-carto-tutorials/osm-rendering-process/, accessed 31 August 2017

Second section ” Design of a Base Map” includes more specific questions, focused on the feedback and suggestions about the created tiled base maps.

In order to assess and to evaluate the results the final solution, the questionnaire was spread within people, all with a background in Cartography or GIS.

4.4. Conclusion

In this chapter, the main techniques which are used to implement a tile-based web map application were clarified. First of all, the design logic of multi-scale base maps *Original*, *Light* and *Dark* was described. Secondly, the implementation workflow was explained, with highlighting each phase (Design, Implementation, Evaluation, and Alteration), required tools and software (OSM Bright styles, OSM data, TileMill, Mapnik, Leaflet and additional web developing tools), and the architecture of the tiled web map application (Client and Server sides). Finally, the background of a questionnaire was discussed in order to provide the evaluation of the created styles *Original*, *Light* and *Dark* for the tile-based web map application.

5. Results

This chapter attempts to provide presentation of the thesis results. It first introduces the initial tiled web map application that has been created, then the questionnaire outcomes are given which are used for updating the tiled web map application.

5.1. Primary designed multi-scale base map application

Created multi-scale tiled web map application is called “WNM”, an abbreviation of the name ‘We Need Maps’, that was chosen by the author initiative, and temporary available at http://188.226.166.167/. The application provides users access to the designed base maps. The initial web-page of the application can be seen in the figure 5.1.

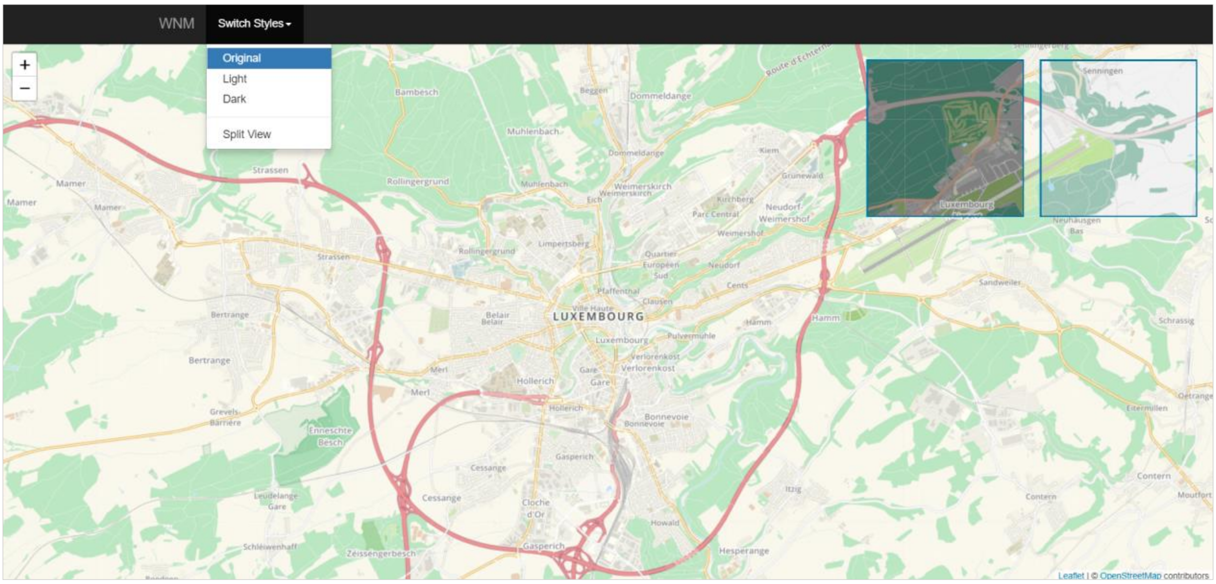


Figure 5.1. *The home page of “WNM” application*

The layout of the application was organized with Bootstrap open-source library and includes a minimalistic graphical user interface (GUI). As demonstrated in the figure 5.1, WNM includes an upper panel and a map view below.

The application panel contains a small menu, that let users switch between the produced map styles, i.e. ‘Original’, ‘Light’ and ‘Dark’. Additionally, users can view a map in a ‘Split View’ mode when all styles are visualized simultaneously, and each style has a third part of the screen size, shown in figure 5.2.

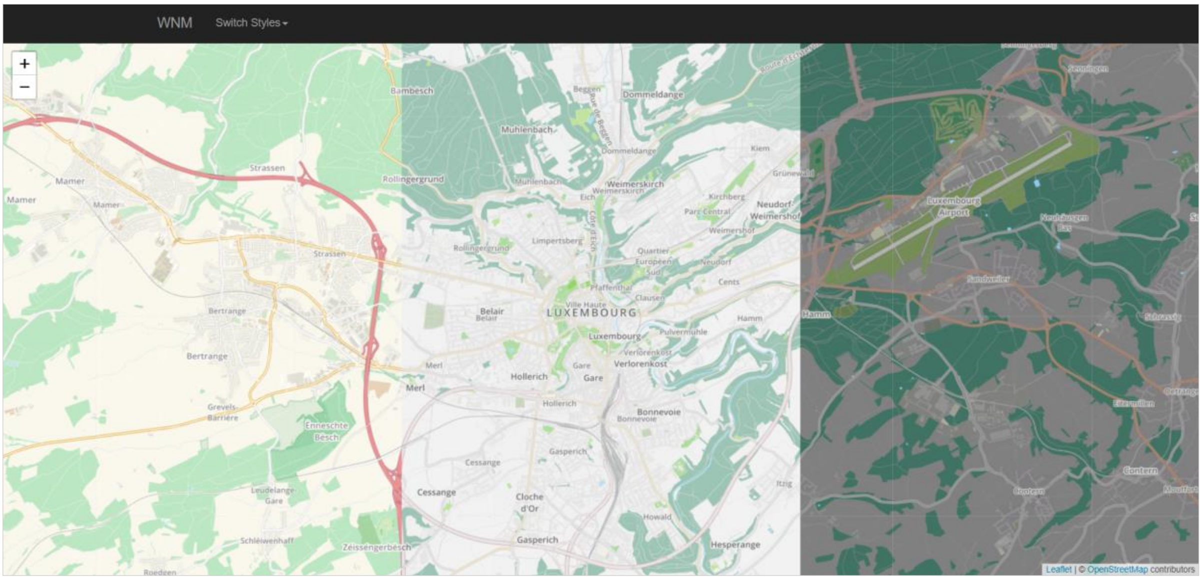


Figure 5.2. *A 'Split View' mode of "WNM" application*

The application also contains some interactivity, e.g. zoom in/out buttons on the upper left corner, and clickable squares on the upper right corner, that let the user switch to the other possible two styles. Moreover, those squares provide a quick overview of other styles at the same zoom level. The clickable squares and 'Split View' mode were aiming a more efficient and comprehensive analysis and comparison of styles, done by survey participants. As a result, users who evaluated the three design solutions provided an extensive feedback.

5.2. Questionnaire results

In total 55 participants responded to the project questionnaire, that was conducted in a period from 24 of August until 4 of September 2017. Participants showed a high response, replies were received for more than 99% of all questions. Afterwards, answers were analysed according to methodological and mathematical rules.

Question 1. In this question it was asked which tiled web map service(s) the user normally uses.

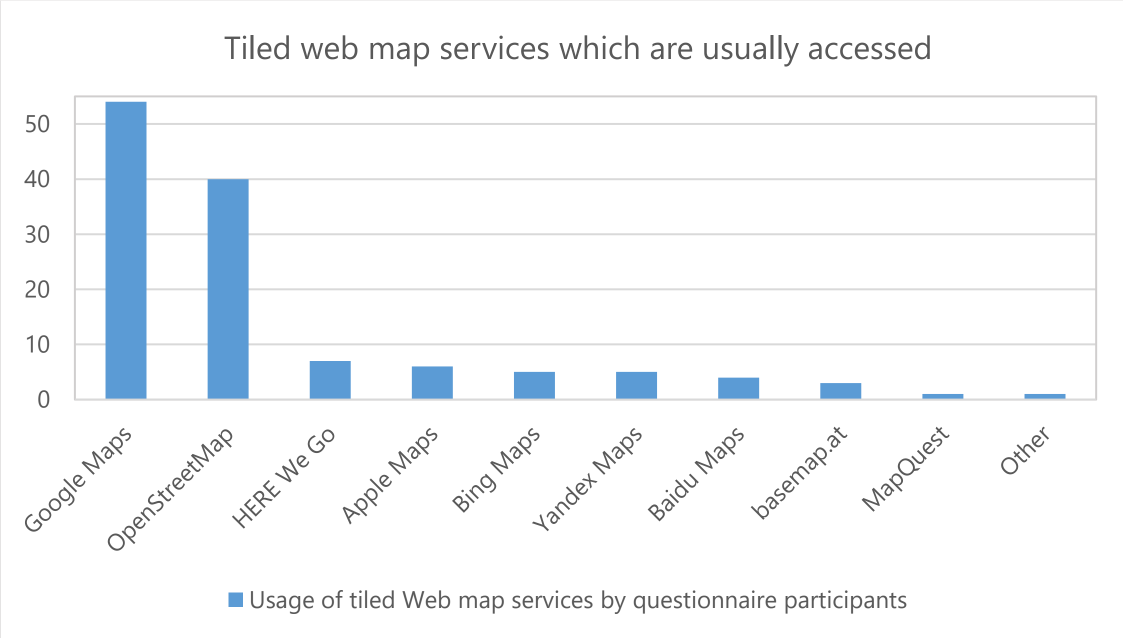


Figure 5.3. *Usage of tiled web map services*

On the upper diagram (Figure 5.3) there are two obvious dominant services, namely Google Maps and OpenStreetMap. It was expected, that Google Maps service will be included because of the leading position on the market of web mapping. Therefore, this test proves that Google Maps is the most commonly deployed tiled web map service.

Nevertheless, there is a back side of such dominance, more known as Googlization which was described by Muehlenhaus in his books (Muehlenhaus, 2014). He said, that *"due to ubiquitous of Google Maps, users expect that all Web maps should look like Google Maps. Its style promotes inaccurate representations, in a sense of web Mercator projection. Moreover, the base map is created and generalized by Google. These reasons are essential in Google Maps hegemony"* (Muehlenhaus, 2014).

OpenStreetMap appearance was also assumed. This demonstrates, that the popularity of open-sources and credibility within their users is high as well (Bartoň, 2009; Behrens, 2014; Grīnfelde, 2016; D. A. Smith, 2016).

Question 2. This question was intended to comprehend which tiled web map services is the favourite one.

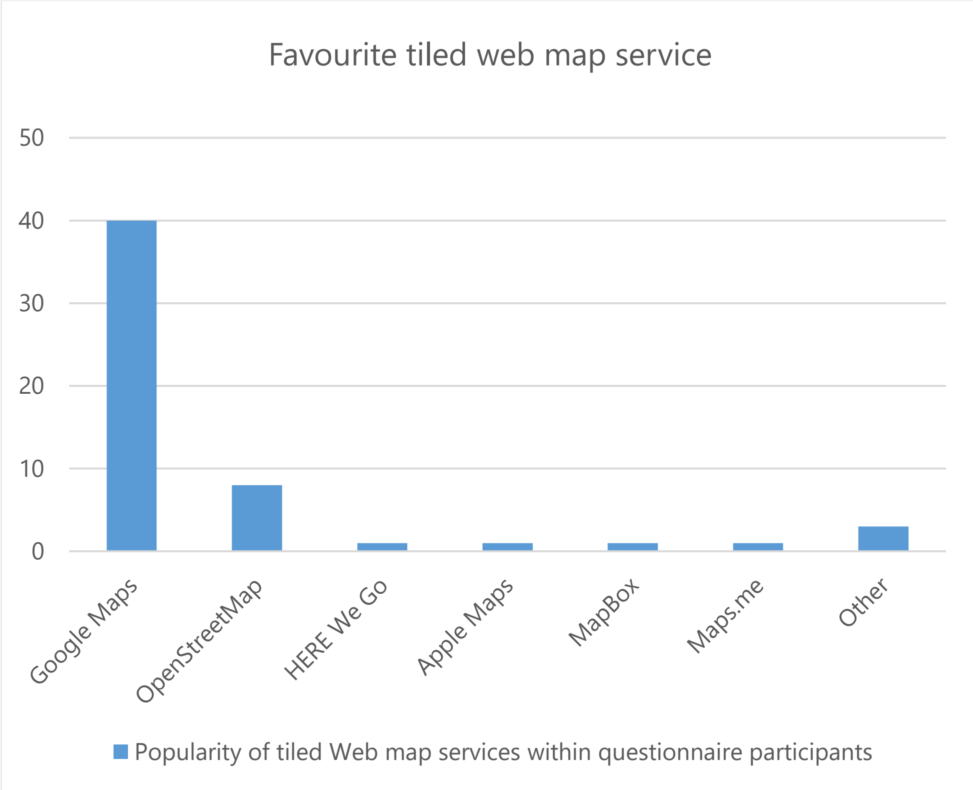


Figure 5.4. *Popularity of tiled web map services*

The result shows (Figure 5.4) that by any means Google Maps remains the leader in the domain of web map service providers.

Question 3. This question has relation to the previous and was mainly aiming at the understanding of motives why users prefer particularly that tiled web map service.

Questionnaire participants were asked to indicate reasons which make them use their favourite tiled web map service. Data was visualized in a squarified tree map structure (Zhou, Cheng, Ye, & Tian, 2017), where the cell size corresponds to the number of votes for certain preference, see figure 5.5. For instance, the most repeated reasons of Google Maps preference are its functionality and services, map design, usability, searching performance etc. OpenStreetMap is chosen because of open-source reason, level of detail, and some other reasons.

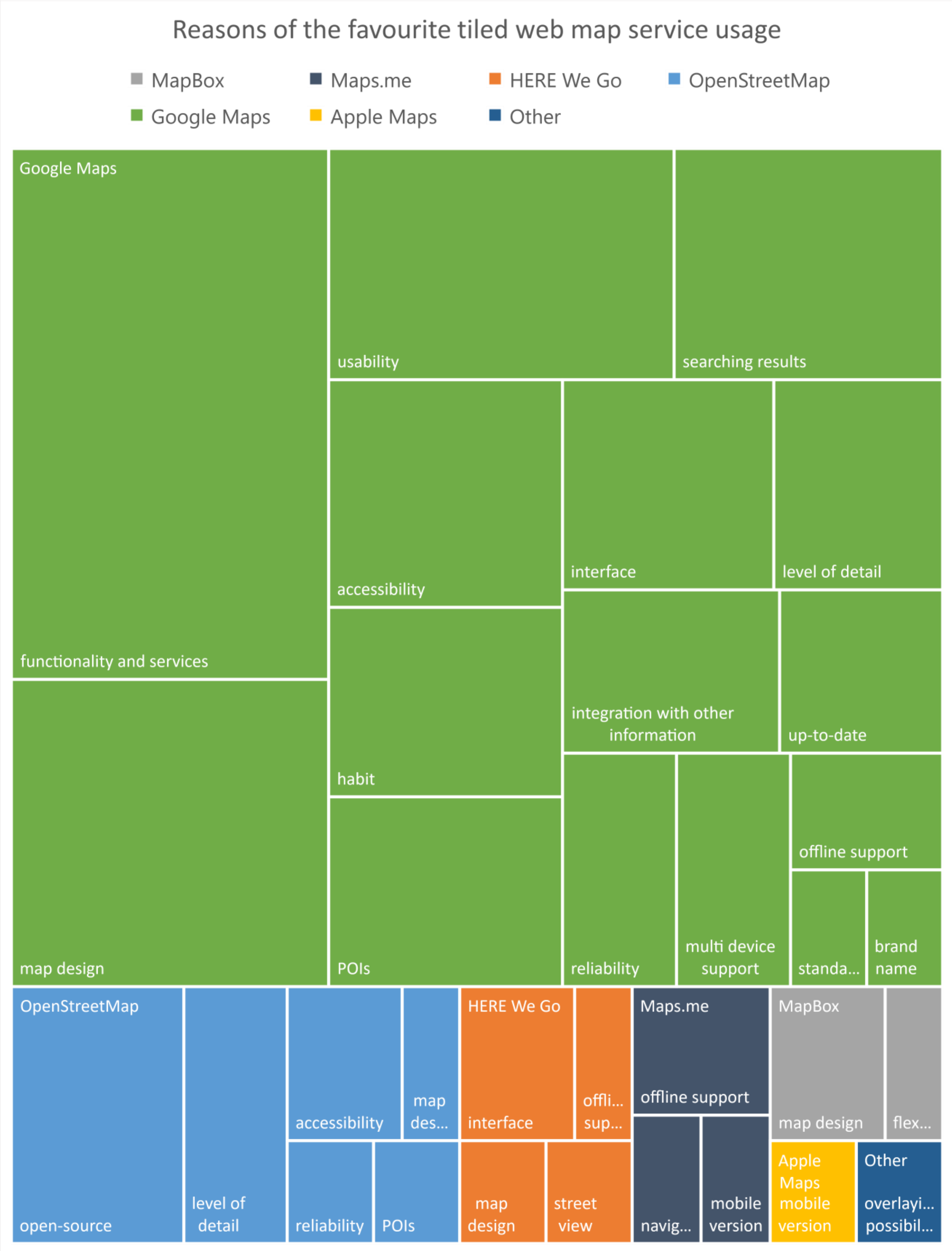


Figure 5.5. *Drivers of tiled web map service usage*

Question 4. The general aim of this question was to analyse the most popular functionality of tiled web map services among the users. The variety of functions were defined after reviewing existing tiles web map services in Section 3.1.

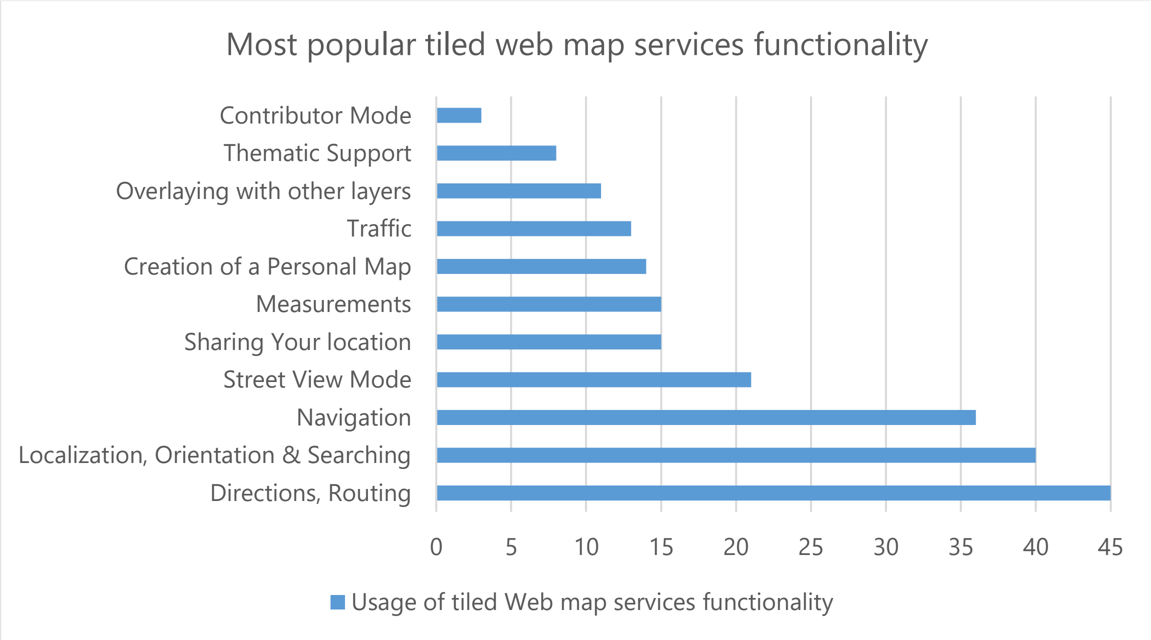


Figure 5.6. *Usage of tiled web map services functionality*

As demonstrated in the figure 5.6 there are three mostly used functions: Direction, routing; Localization, Orientation and Searching; and Navigation. More than 35 participants voted for those functions. Moreover, roughly 42% participants specified usage of a Street View Mode. Approximately 23% of participants indicated their usage of tiled base maps with other layers overlaying.

Question 5. This question was designed to comprehend whether users need a map legend when they are deploying a tiled web map service?

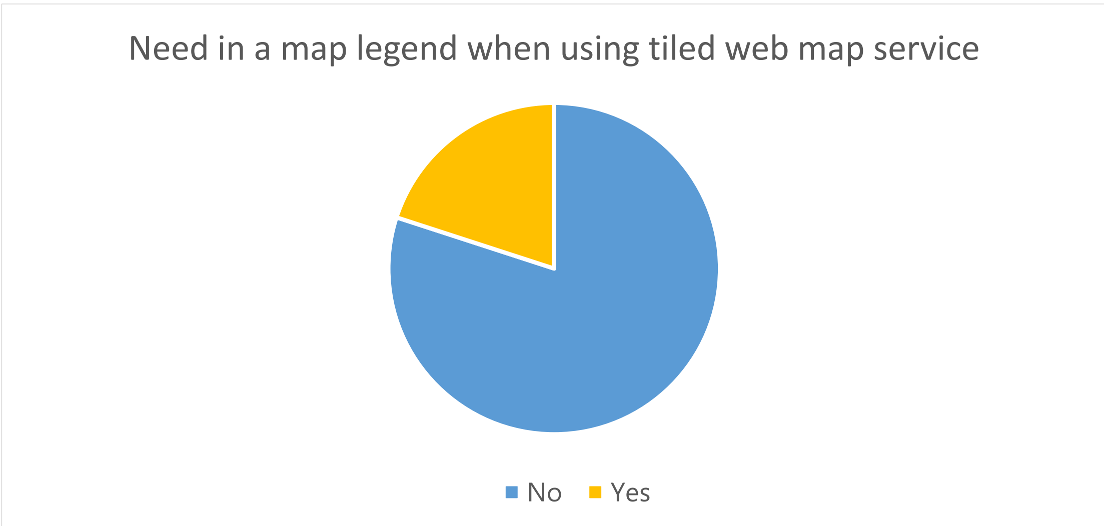


Figure 5.7. *A need of map legend in tiled web map services*

Responds to this question shown that only 20% of questionnaire participants need a map legend when using a tiled web map service. However, it does not confirm the fact that a map legend is not required when a tiled web map service is opened in GIS software for various purposes. This needs further research.

Question 6. In this question, participants were asked to give their opinion about the tiled base map produced in *Original* style.

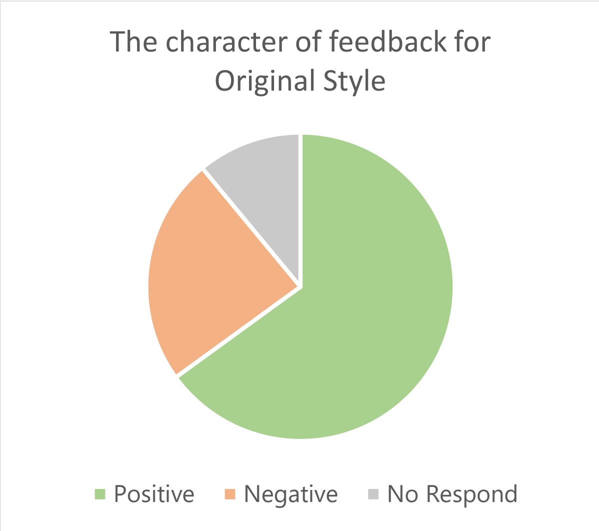


Figure 5.8. *Feedback for Original Style*

More than 60% of users' feedback was positive which in general says that users liked the map, produced in Original Style. However, this does not mean, that users will find this map useful when opening in GIS software, further investigations are required.

In the figure below (Figure 5.9) more detailed explanation of the feedback for Original Style is visualized with a slice-and-dice tree map (Zhou et al., 2017).

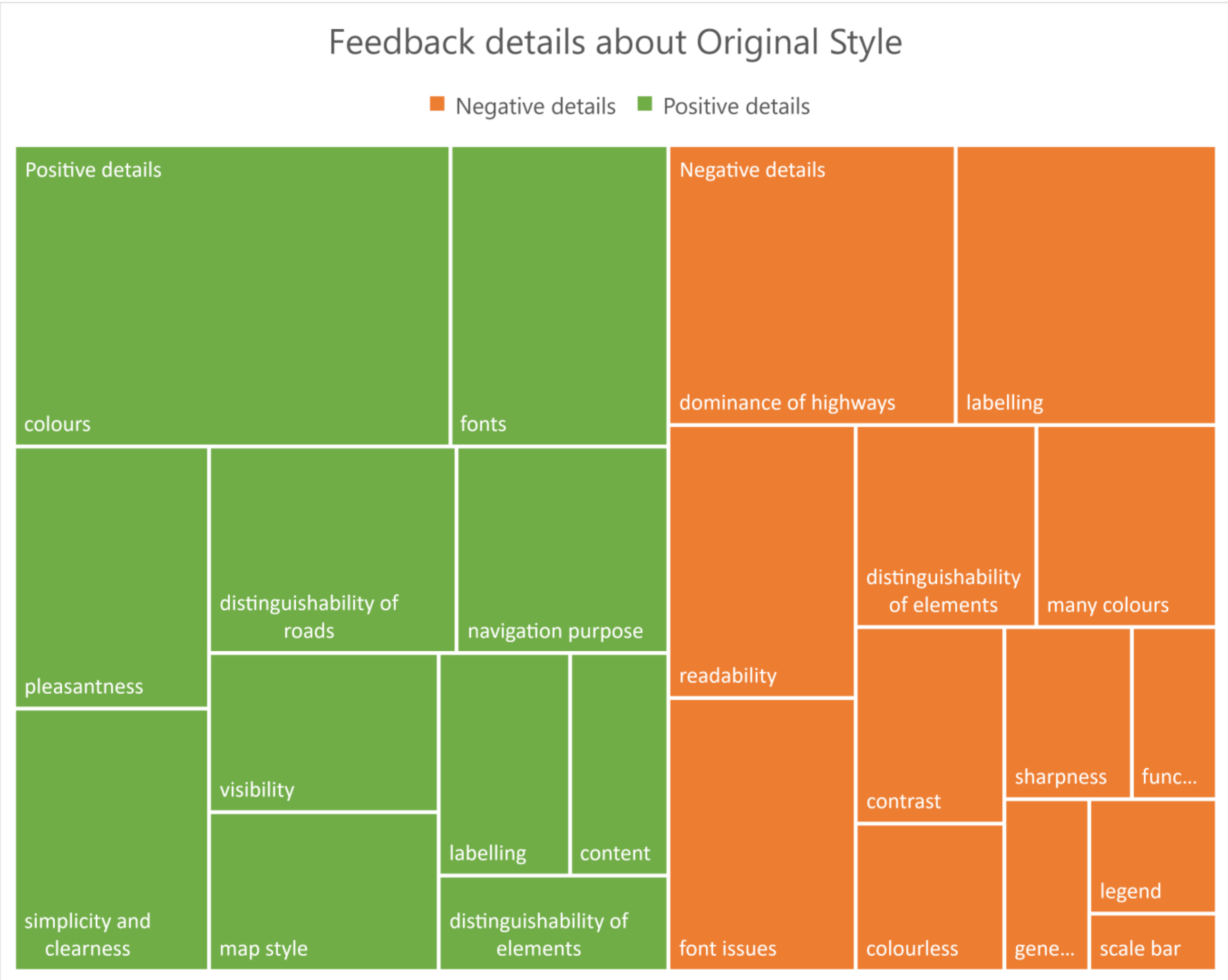


Figure 5.9. *A tree map of feedback details about Original Style*

Question 7. In this question, participants were asked to give their opinion about the tiled base map produced in *Light* style.

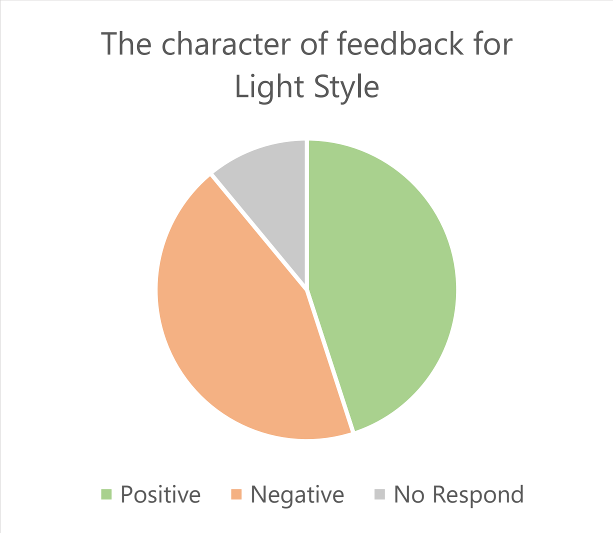


Figure 5.10. *Feedback for Light Style*

The difference between positive and negative feedback is only 1% which does not prove that this is a nicely designed map. However, the map should be tested and evaluated for usability and performance in GIS software in future research.

In the figure below (Figure 5.11) more detailed explanation of the feedback for Light Style is visualized with a slice-and-dice tree map (Zhou et al., 2017).

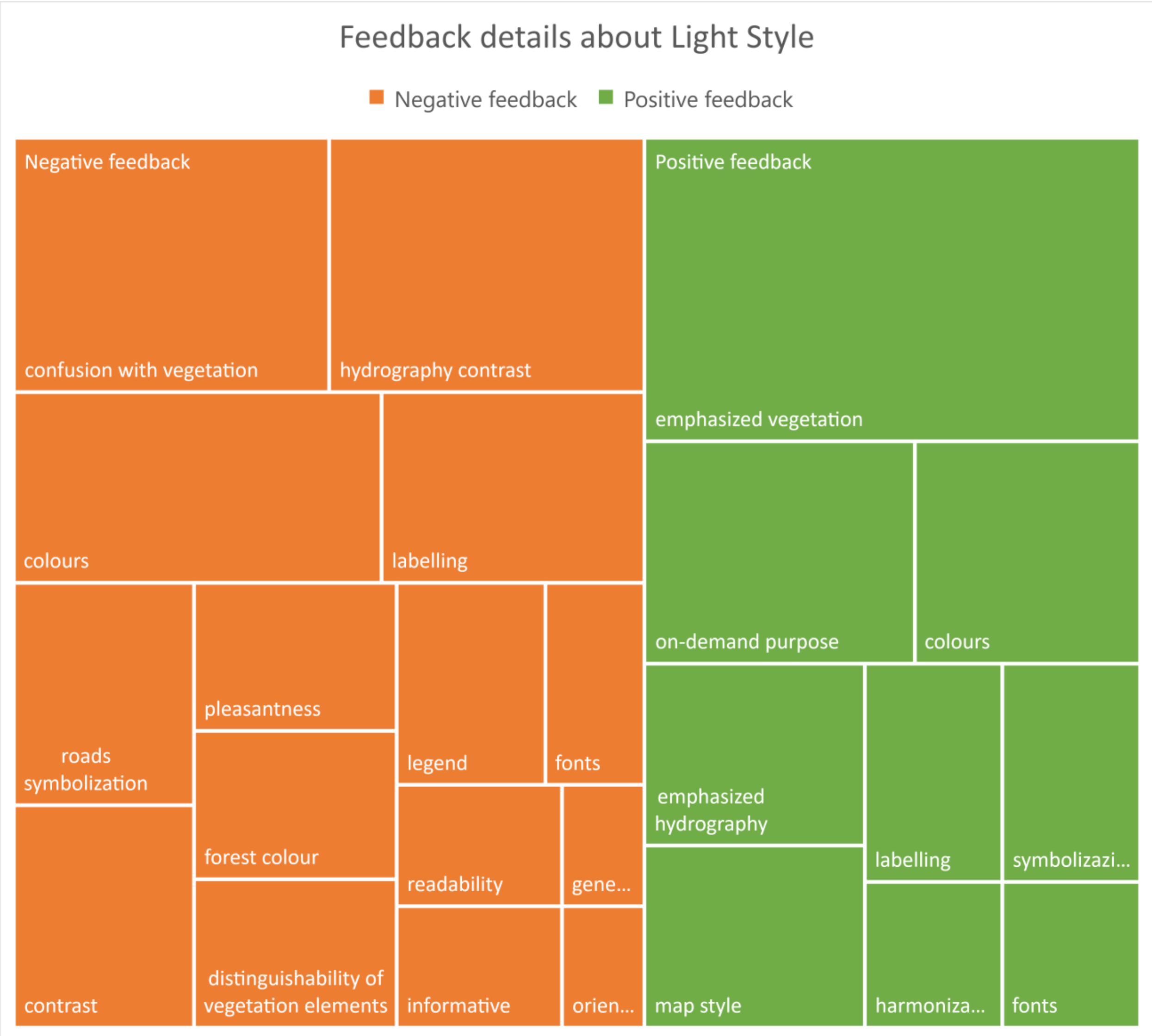


Figure 5.11. *A tree map of feedback details about Light Style*

Question 8. In this question, participants were asked to give their opinion about the tiled base map produced in *Dark* style.

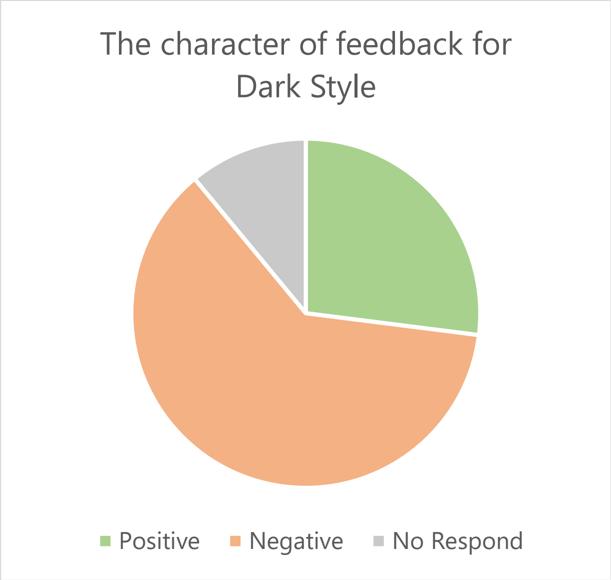


Figure 5.12. *Feedback for Dark Style*

More than 60% of users' feedback was negative which in general leads to users unsatisfactory. Therefore, the map styles must be adjusted and evaluated additionally. Furthermore, the map should be examined in GIS software, in future investigations.

In the figure below (Figure 5.13) more detailed explanation of the feedback for Dark Style is represented with a slice-and-dice tree map (Zhou et al., 2017).

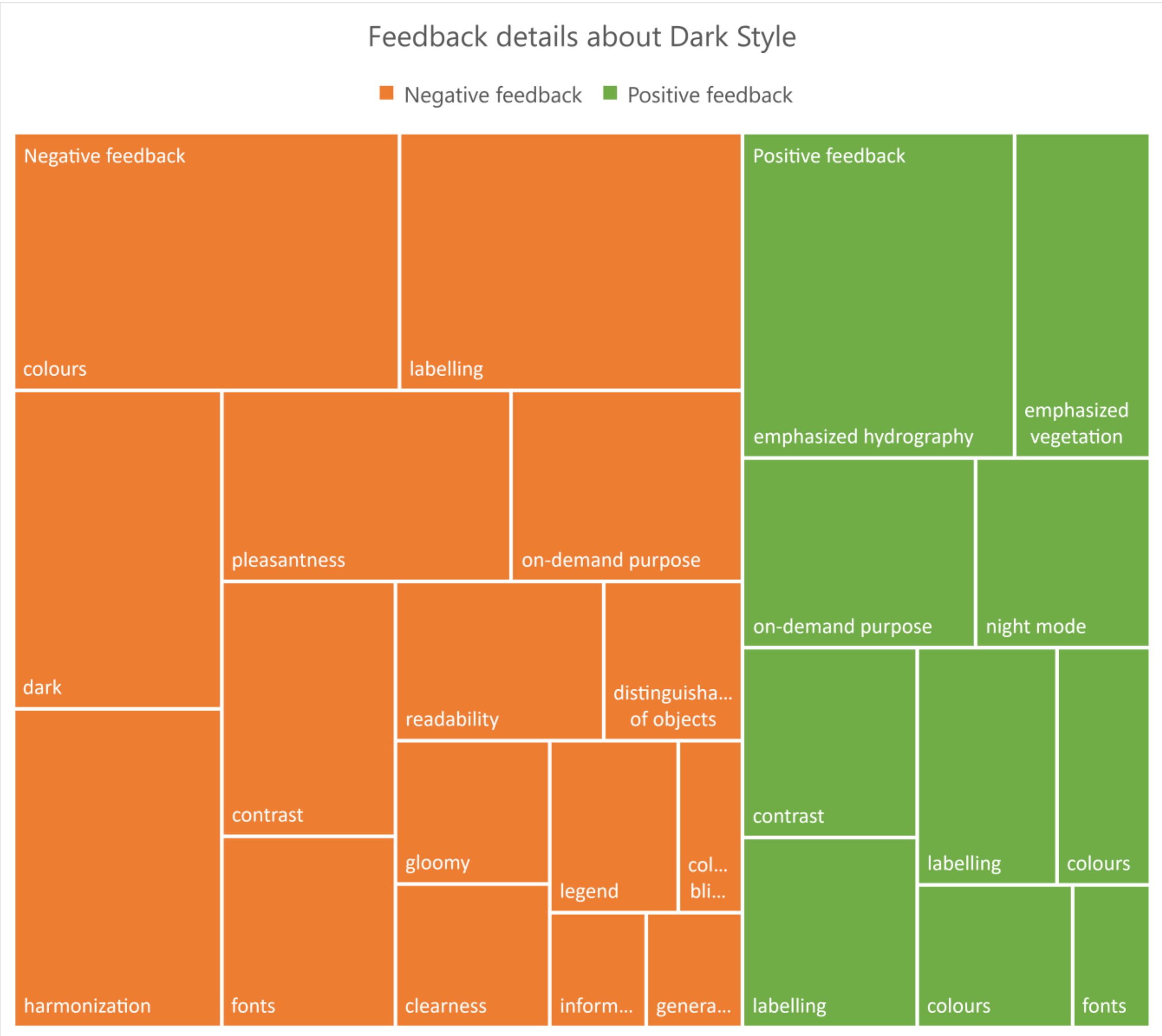


Figure 5.13. *A tree map of feedback details about Dark Style*

5.3. Updated multi-scale base map application

Based on the conclusions of the questionnaire results it was decided to apply next changes:

- Improve *Original* map in the context of negative issues: dominance of highways, readability, labelling, distinguishability of elements, contrast and colours.
- Improve *Light* map style in the context of negative issues: confusion with vegetation diversity, hydrography contrast, labelling, colours, contrast, forest colour, distinguishability of vegetation objects and roads symbolization.
- Delete *Dark* map style which was unsatisfactory assessed by users.

In the figure 5.14 the updated version of a tiled web map application is demonstrated. It is temporary available at http://188.226.166.167/v2/index.html.

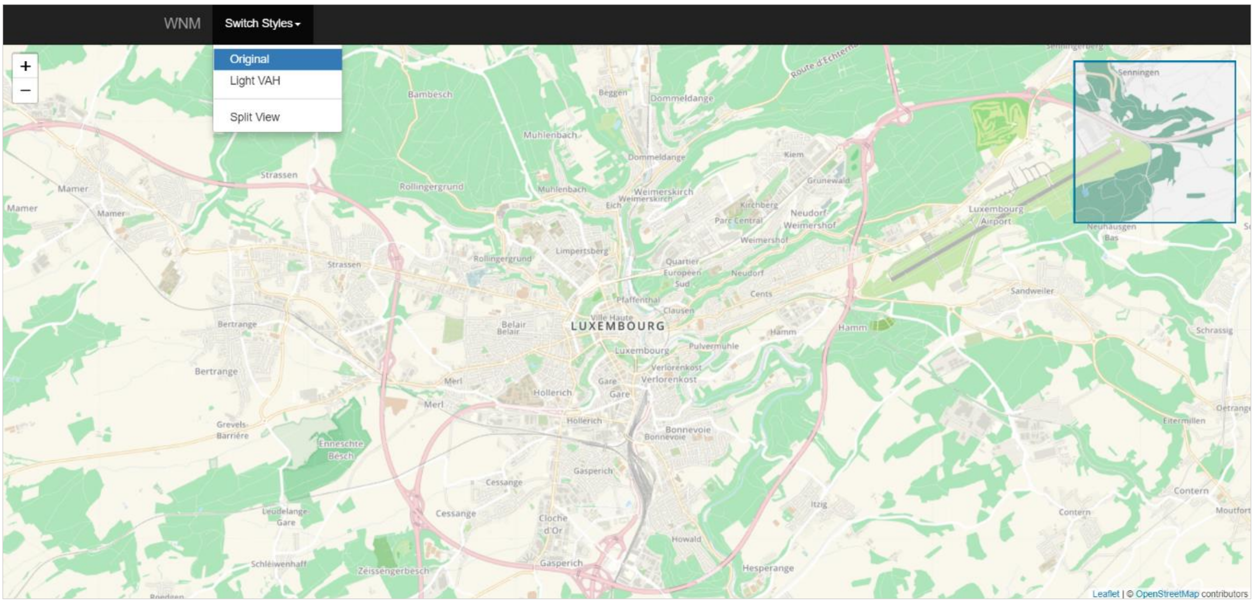


Figure 5.14. *The home page of updated "WNM" application*

5.4. Conclusion

In this section, the thesis results were explained. Firstly the initial version of the tiled web map application that includes *Original*, *Light* and *Dark* base map styles was described. Later the questionnaire results were discussed in detailed which let to emphasize problems in produced tiled web map application, particularly in the base maps. Finally, tiled web map application was adjusted and changed in order to meet users' wishes and desires. As the result, only *Original* and *Light* base map styles were adopted.

6. Conclusion and recommendations

Till now, usage of raster tile-based map architecture remains the major approach in building web maps and tiled web map services. However, pre-rendered raster tiles have a lack in flexibility in the context of design, styles and content. Consequently, it influences on the usability of multi-scale base maps and do not accomplish user requirement and needs.

The main aim of this research was to produce a multi-scale base map with a pre-defined design that meets the requirements of users and set it with an access on the Internet as a tested prototype of a tile-based web map service. It was done through the examination of the related work and examples in multi-scale base map design, and critical review of multi-scale base maps produced by well-known web map providers. Additionally, tiling schemes and standards, that provide appropriate and structured way of launching tiled web map services were also explained.

Furthermore, in this thesis the background of vector tiles was discussed. The application of vector tiles adds some flexibility in the styling of tiles and it becomes more feasible within last year, rather than raster tiles. However, the design of multi-scale base maps in most cases remains in the plane of raster tiles and the implementation of vector tiles remains an issue in daily usage.

6.1. Discussion

The final results met initial Master Thesis objectives, that were core drivers of current research. Generally, they let to:

- Determine the methodology for styling and rendering of the OpenStreetMap data into a tiled web map;
- Produce a multi-scale base map for the web map application, that satisfies user needs;
- Align specifications for zoom levels, generalization, content, styling, symbolization, and other technical specifications;
- And finally, build a prototype of a tile-based web map service.

Moreover, certain research questions were answered in this Master project.

Question 1 – *"How should the base map be designed to meet the requirements of users of GIS software?"*

User-centred design (UCD) plays significant role in the context of developing user-friendly map applications. Therefore, when designing a mapping product, developer has to consider user requirements, that are initial and essential in the iterative design cycle. Moreover, the context of use can also facilitate appropriate creation.

Base map design must be conducted according to certain cartographic criteria and map usage purpose. It will ensure appropriate on-demand base map creation. Additionally, the design of multi-scale base maps can be facilitated by the analysis of existing base maps which were styled by other developers, and the critical review of base maps provided by web map services which are used for wide masses.

However, created base map should be additionally evaluated by experts and tested by users, according to cartographic design and usability requirements. After the evaluation, the base map can be adjusted towards user feedback or experts recommendation. Such cooperation will meet user requirements and provide high satisfactory by users.

Question 2 – *"How appropriate are TileMill and Mapnik as a software and a tool to style and render OpenStreetMap data?"*

TileMill is a nice example of a software with GUI, where developer can modify styles and define various parameters for tiled web maps. It is beneficial in a sense of dynamic demonstration of applied changes, possibility to import and export data in various file formats, explicit documentation and manuals, and it is supported by major OS.

Mapnik is one of the dominant and commonly used software for rendering and producing tiles for tiled web map services. Mapnik is exploited by many well-known mapping companies, such as OpenStreetMap, MapBox, CartoDB, Stamen, MapQuest, and Kosmtik. It is also possible to apply commands in several major programming languages, i.e. C++, Python, and Node. However, official documentation and tutorials for Mapnik require some improvements and completeness.

TileMill and Mapnik are usually implemented for styling and rendering the OSM data, which is an open-source, standardized, and can be easily retrieved and manipulated. OSM data is commonly stored in databases which allow more efficient and organized way of its accessing. OSM data is frequently used by many developers, and till now remains a major source of VGI.

6.2. Recommendations

In this project, the questionnaire that was conducted has shown, that the produced multi-scale base maps contain certain design issues and uncertainties. Consequently, map design improvement is essential to fulfil target user requirements and needs and to reach usability goals.

Improving and mastering the multi-scale map design is an iterative process which can be determined by the user-centred design (UCD) cycle. In future study, the design of a multi-scale base map can be accomplished with several stages, based on the results of a usability test, demonstrated in the figure 6.1.

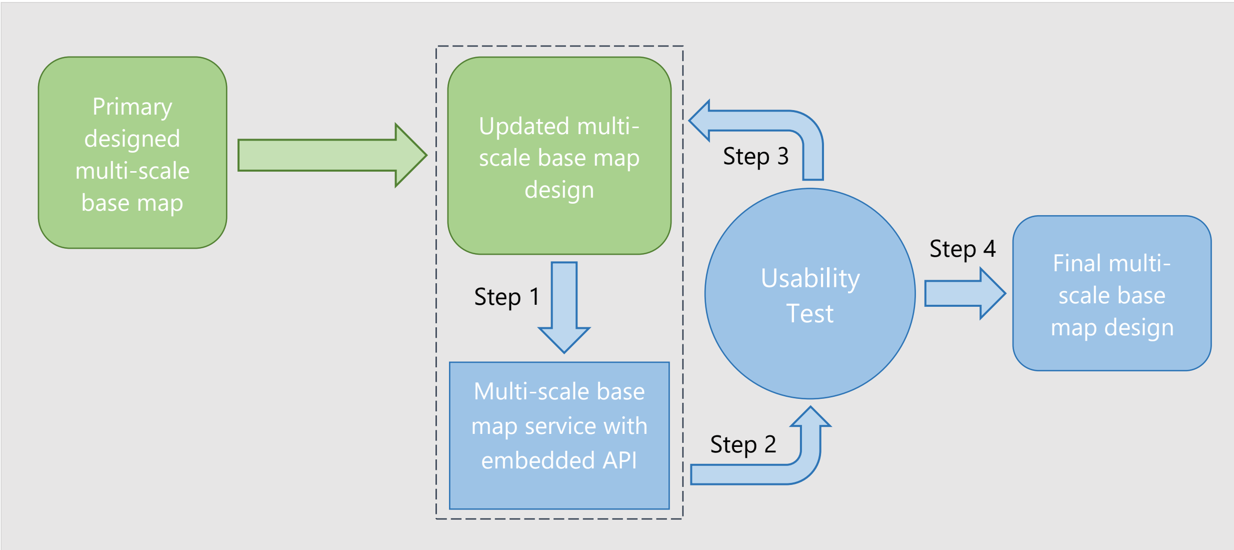


Figure 6.1. *Future steps towards the Usability test*

Step 1. After updating the multi-scale base map design an API should be embedded in the service, that provides access to the multi-scale base map. This step could be supported by ILWIS professional programmers, to ensure a possibility to render OSM data for the whole world and to conduct a usability test in ILWIS or any other GIS software.

Step 2. This step leads to the usability test, that has to be conducted in order to evaluate qualitatively the multi-scale base map effectiveness, usefulness, and functionality. The main purposes of base maps are localization, orientation, and thematic support. Therefore, suitable practical tasks have to be accomplished with appropriate assessment methodology. Usability test should be addressed to GIS users, who are the targeting group of the multi-scale base maps usage. Additionally, the usability test addresses experts, who particularly deal with tiled web services in GIS software. This may lead to the improvement of the tiled web application performance.

Step 3. The multi-scale base map has to be updated with usability test outcomes which are specified in terms of UCD. Hence, the cycle between Steps 3, 4 and 5 is continuing until the usability goals can be achieved.

Step 4. After positive usability test, a multi-scale base map can be widely deployed and supplied as a default tiled web map service within a GIS software.

7. Appendix - Project questionnaire

Let's create a perfect Base Map together

Hello, dear participant! Thank You for not being indifferent.

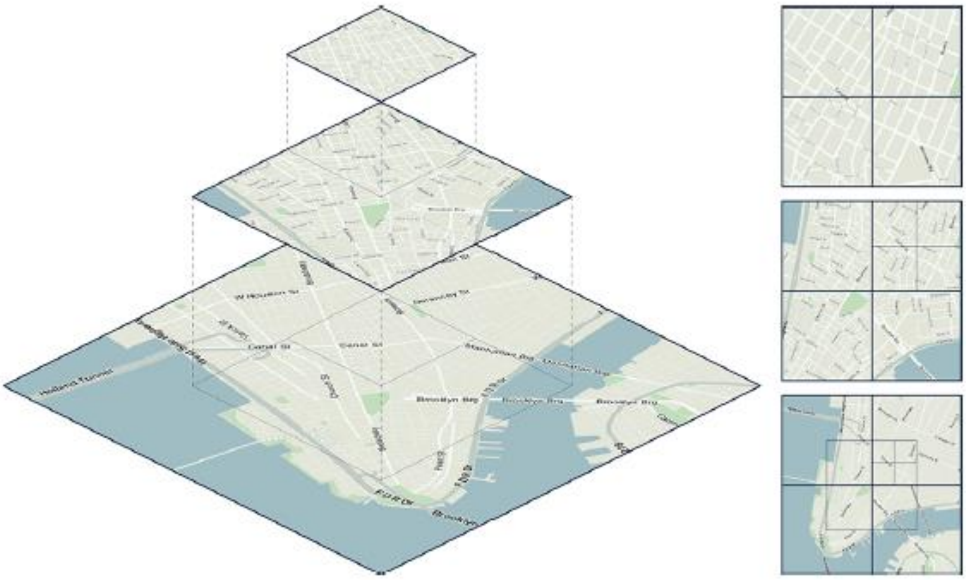
On the next slide, I will provide You with brief notes that may lead to better dialogue between me and You, dear participant.

Let's make our world better. Good luck!

Tiled Base Map: Introduction and Background.

A Tiled Base Map (Slippy Map) is a map, which is displayed in a browser (or software window) by seamlessly joining dozens of individually requested image files over the Internet. Tiled Base Map construction approach is used by a large number of Web Maps and Map Services. The best-known examples are Google Maps, OpenStreetMap, Bing Maps, Here, MapQuest, Yandex Maps.

Tiled Base Map scheme



Advantage

Map delivery based on Tiles helps to speed the display of map through the Internet, reduce data transmission volumes, and provide a number of other benefits, e.g. optimise the performance of a web map applications etc.

Problem

Not all of Tiled Base Maps on the Web, as well as Tiled Web Map services [such as Tile Map Service (TMS) or Web Map Tile Service (WMTS)] which are used in GIS software, have appropriate Map design that suits user needs and requirements, which leads to better usability.

Usage of a Base Map Service

1. **Which Base Map service(s) do You normally use? (Note 1: You can select more than one. Note 2: If You use any other local service which is popular in Your country, please indicate it also.)**

Check all that apply.

- [ ] Google Maps
- [ ] OpenStreetMap
- [ ] Bing Maps
- [ ] Here Maps
- [ ] MapQuest
- [ ] Apple Maps
- [ ] Yandex Maps
- [ ] Baidu Maps
- [ ] Bhuvan
- [ ] Géoportail
- [ ] TerraServer-USA
- [ ] Other: ____________________

2. **Which Base Map service(s) is(are) Your favourite?**

____

3. **Why do You prefer that particular Base Map service(s)?**

____
____
____
____
____

4. **What are the main purposes of Your Base Map service usage?**

Check all that apply.

- [ ] Directions / Routing
- [ ] Traffic
- [ ] Navigation
- [ ] Localization, Orientation & Searching
- [ ] Measurements
- [ ] Thematic Support
- [ ] Overlaying with other layers
- [ ] Street View Mode
- [ ] Creation of a Personal Map (for example, Collecting and Visualization of places that You have visited)
- [ ] Sharing Your location (for instance, in Social Media or with your Friends, Relatives or Parents)
- [ ] Contributor Mode (Contribution to the Web Map service development, e.g. uploading of points of interest (POIs) etc.)
- [ ] Other: ____________________

5. **Do You need a Map Legend when You use a Tiled Base Map service?**
Mark only one oval.

- Yes
- No

Design of a Base Map

Please, open the link in your browser: http://188.226.166.167/. There You will access a Base Map produced in three styles: Original, Light & Dark. You are kindly asked to give opinions about each Map based on some Criteria, e.g. style pleasantness, colours, fonts and labeling, symbolization, content at each scale level, scale level transition, performance etc.

6. **Please, can You give Your opinion about the Original map: http://188.226.166.167/index.html. It was mainly designed as a background map for overlaying with other layers, localization and orientation in GIS software.**

7. **Please, can You give Your opinion about Light map: http://188.226.166.167/light.html. It was mainly designed for hydrographic and vegetation objects analysis in GIS software.**

8. **Please, can You give Your opinion about Dark map: http://188.226.166.167/dark.html. It was mainly designed for hydrographic and vegetation objects analysis in GIS software.**

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